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Transforming Agrifood Systems in The Face of Climate Changes and Energy Transitions

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Ecological Assessment and Conservation Implications for *Ulmus wallichiana* (Planch.) in Kullu Forest Division, Himachal Pradesh

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Abstract: The present investigation to assess the phytosociological and natural regeneration status of *Ulmus wallichiana* (Planch.) from three ranges i.e., Kullu, Patlikuhl, and Naggar of the Kullu forest division, Himachal Pradesh were selected. From each range, three sites were chosen randomly. The overall highest (145.74) IVI (Important Value Index) of tree species was for *U. wallichiana* and the overall highest (178.68) IVI of shrub species was for *Rosa moschata* in the Babeli site in the Kullu range. The maximum Shannon index and species richness i.e., 2.427, and 2.589 was observed in the Badagram population of Ulmus for tree species whereas for shrub species maximum Shannon index (1.988) and species richness (1.791) was observed in the Dhobi population. The natural regeneration of *U. wallichiana* was maximum (7.5%) at the lower altitudinal range (1100-1500m) and minimum (3.75%) at the higher altitudinal range (1800-2100m). *U. wallichiana* has been identified as a vulnerable species, therefore, the major species is essential from an immediate in-situ and ex-situ conservation point of view.

Keywords: Conservation, Diversity, Phytosociological, Population, Regeneration

Elms are deciduous and semi-deciduous trees of the genus *Ulmus* of the family Ulmaceae with roughly 30 to 40 different species (Zhang et al 2022) that grow between 800 to 3000 meters above sea level. It is found in Afghanistan, Pakistan, Northern India and Western Nepal (Nazima Batool et al 2014). This species is found in India in the states of Jammu and Kashmir, Uttarakhand, and Himachal Pradesh. The Himalayan elm may grow to a height of 30 meters and has a broad canopy with ascending branches. The bark on the trunk is greyish-brown and wrinkled lengthwise. The leaves are elliptic-acuminate, with a length of less than 13 cm and a breadth of less than 6 cm. The blooms have a diameter of less than 13 mm and are known as samara. They grow in clusters of branches and blossom between March and April (Arya et al 2013). Elm leaves provide good feed, and the bark produces a strong fiber that can be used to make cordage and rope. The bark of *Ulmus wallichiana* is widely used in Himalayan traditional medicine to treat shattered bones in both animals and humans (Arya and Agarwal 2008). According to the IUCN Red List, *U. wallichiana* is vulnerable (IUCN 2016). Heavy lopping for fodder and fuelwood, as well as the removal of fibrous bark for rope making, decimated the tree and rendered it incapable of reproducing naturally through seeds. The high proportion of empty seeds hinders the natural regeneration of the species. Cuttings are also difficult to root making vegetative propagation problematic (Mughal and Mugloo 2016).

Regeneration is the most critical mechanism for maintaining a community's stable age structure of plant species, which is influenced directly or indirectly by numerous climatic and edaphic conditions. In forest management, a regeneration study illustrates not only the current state of the forest but also hints at future forest composition changes (Sharma et al 2014, Malik and Bhatt 2016). In the Indian Himalayan Region (IHR) changes in the structure, composition, and regeneration of natural forests are being caused by climate change and environmental disturbances. The Himalayan forests are vulnerable to significant climate change effects because they are frequently dominated by low-temperature conditions (Wester et al 2019). Poor regeneration due to habitat loss, land degradation, deforestation, forest fires, overgrazing, lopping, etc. is the major problem of mountain forests (Parveen et al 2017, Pant and Samant 2012). The conservation status of *Ulmus wallichiana* in the western Himalayas (Nazim Batool et al 2014), in Pakistan (Khan et al 2021) and the analysis of the phytosociology and regeneration status of the Elm tree were earlier studied by Kumar and Sharma 2014. In the current investigation, the ecological status and regeneration potential of *U. wallichiana* Planch was carried out in the Kullu forest division of Himachal Pradesh.

MATERIAL AND METHODS

Study area: The study was conducted in the Kullu Forest Division of Himachal Pradesh, India. The climate is typical of the temperate zone at higher altitudes, above 1000 meters and subtropical at lower elevations. The Kullu district forms a transitional zone between the Lesser and Greater

Himalayas. It is characterized by high NW-SE trending ridges and deep river valleys, several of which in their upper reaches bear imprints of glacial activity in the near past. The area generally represents young, immature topography, controlled by the underlying rocks' structure and lithology. The study was carried out from 2020 to 2022 at three ranges i.e., Kullu, Patlikuhl, and Naggar of the upper Beas valley of district Kullu. Three sites were further selected from each range for the survey (Table 1).

Experimental methodology: The study on the phytosociology of forests was carried out after laying out sample plots in each of the selected sites. The observations for trees and shrubs were recorded by laying quadrats of size (30m × 10m). In each site, 5 quadrats were laid out and the Importance value index (IVI), similarity/dissimilarity index, diversity indices, Simpson index, Shannon index, equitability, and species richness index were recorded. The survey was carried out from the rainy season onwards to study the regeneration status of major species. Observations on regeneration were made in a recording unit (quadrat) size by the species-area curve method. The recruits, un-established and established regeneration was computed using the following:

$$\text{Recruit (r) / ha} = \frac{2500 \times \text{total number of recruits}}{\text{Total number of recording units}}$$

$$\text{Unestablished (u) / ha} = \frac{2500 \times \text{total number of unestablished plants in sampling units}}{\text{Total number of recording units}}$$

$$\text{Established (e) /ha} = \frac{2500 \times \text{total number of established plants in sampling units}}{\text{Total number of recording units}}$$

RESULTS AND DISCUSSION

Phytosociological study: The phytosociological studies revealed the floristic composition of trees and shrubs in the natural population of *Ulmus wallichiana* growing. The maximum number of trees was in Badagram (11) followed, by Dhobi, Seonidhar, Pulang and Rumsu (10), Mohal and Babeli (9), Shamshi and Naggar (8) (Table 2). The maximum number of shrubs was found in Dhobi (11), followed by Badagram and Seonidhar (9), Naggar, Pulang and Rumsu (6), Babeli (5), and the minimum in Shamshi and Mohal (4).

Importance value index (IVI) : The most dominating species was *Ulmus wallichiana* with a maximum (145.74) IVI value in the Babeli site followed by *Robinia pseudocasia* (74.94), *Populus deltoides* (70.74) in the Mohal site whereas, the least dominating species was *Morus serrata* (10.40) in Babeli site, in the Kullu range (Table 3). The most dominating shrub species was *Rosa moschata* with a maximum (178.68) IVI value followed by *Prinsepia utilis* in the Mohal site whereas, the least dominating species was *Indigofera heterantha* in the Shamshi site, in the Kullu range.

Diversity Indices

Similarity and dissimilarity indices: The similarity index in *Ulmus* growing population of fourteen species ranged from 0.09 to 0.95 (Table 4) maximum in Pulang and Naggar (0.95), and minimum in Rumsu and Naggar (0.09). The dissimilarity index for trees ranged from 0.05 to 0.89. The maximum was recorded in Pulang and Mohal, Rumsu and Mohal (0.89) whereas a minimum (0.05) was in Pulang and Naggar. The species present in sites Pulang and Naggar depicted the highest similarity because these two populations were under the same range. Rumsu and Naggar are so far apart from each other, hence there are fewer similarities in trees and shrubs.

The Similarity index for the shrubs in *Ulmus*-bearing populations ranged from 0.16-0.75 maximum in Seonidhar and Shamshi (0.75) populations and a minimum in Dhobi and Seonidhar (0.16) populations. The dissimilarity index for shrubs ranged from 0.25 to 0.84 and was maximum in Seonidhar and Dhobi (0.84) populations, whereas a minimum (0.25) was in Seonidhar and Shamshi.

Simpson index (D): The Simpson index for tree species in the *Ulmus* growing population was a maximum (0.881) for Pulang and a minimum (0.667) for Mohal (Table 5). In the

Table 1. Selected sites in Kullu forest division of Kullu district (HP)

Ranges	Sites	Latitude (°N)	Longitude (°E)	Altitude (m)
Kullu	Shamshi	31.89	77.13	1100-1250
	Mohal	31.91	77.11	1250-1350
	Babeli	32.00	77.12	1350-1500
Patlikuhl	Badagram	34.77	73.13	1500-1600
	Seonidhar	31.95	77.15	1600-1700
	Dhobi	32.08	77.12	1700-1800
Naggar	Naggar	32.11	77.16	1800-1900
	Pulang	32.03	77.23	1900-2000
	Rumsu	32.11	77.17	2000-2100

Table 2. Floristic composition of trees and shrubs in the natural population of *Ulmus wallichiana*

Species	Trees								
	Kullu			Patlikuhl			Naggar		
	Shamshi	Mohal	Babeli	Badagram	Seonidhar	Dhobi	Naggar	Pulang	Rumsu
Abies pindrow	-	-	-	-	-	-	-	-	-
Aesculus indica	-	-	-	-	-	-	-	-	-
Ailanthus altissima	-	-	-	-	-	+	-	-	-
Alnus nepalensis	-	-	-	+	+	+	-	+	+
Betula alnoides	-	-	-	-	-	-	-	-	-
Cedrus deodara	-	+	-	+	+	+	-	+	+
Celtis australis	+	+	+	-	-	-	+	-	-
Eucalyptus globulus	-	-	+	-	-	-	-	-	-
Ficus palmata	+	+	+	+	+	-	+	+	+
Jacaranda mimosifolia	-	-	-	-	-	-	-	-	-
Juglans regia	-	+	-	+	+	+	+	+	+
Melia azedarach	+	+	+	-	-	-	-	-	-
Melia composita	-	-	-	+	+	+	-	+	+
Morus alba	+	-	-	-	-	-	-	-	-
Morus serrata	+	-	+	+	+	+	-	+	+
Piceasmithiana	-	-	-	+	+	+	-	+	+
Pinus wallichiana	-	-	-	+	+	+	+	+	+
Pistacia integerrima	+	-	+	-	-	-	-	-	-
Platanus orientalis	-	+	-	-	-	-	-	-	-
Populus ciliata	-	-	-	-	-	-	-	-	-
Populus deltoides	-	+	-	+	-	-	-	-	-
Populus nigra	-	-	-	-	-	-	-	-	-
Pyrus pashia	+	-	-	-	-	-	-	-	-
Robinia pseudocacia	-	+	+	-	-	-	+	-	-
Sapindus mukorosii	-	-	-	-	-	-	-	-	-
Sterculia urens	-	-	-	-	-	-	+	-	-
Toona serrata	-	-	+	+	+	+	+	+	+
Ulmus wallichiana	+	+	+	+	+	+	+	+	+
Total	8	9	9	11	10	10	8	10	10
Shrubs									
Berberis lycium	-	+	+	+	-	+	-	-	-
Bochmeria mivea	-	-	-	+	+	+	-	-	-
Daphne cannabina	-	-	-	+	-	+	+	+	+
Debregeasia hypoleuca	-	-	+	-	-	-	-	-	-
Indigofera heterantha	+	-	-	+	+	+	+	+	+
Prinsepia utilis	+	+	+	+	+	+	+	+	+
Rosa macrophylla	-	-	-	-	-	-	-	-	-
Rosa moschata	+	+	+	+	+	+	+	+	+
Rubus ellipticus	+	+	+	+	+	+	+	+	+
Rubus niveus	-	-	-	-	+	+	-	-	-
Sarcococca saligna	-	-	-	-	-	-	-	-	-
Skimmia laureola	-	-	-	+	+	+	-	-	-
Strobilanthes glutinosus	-	-	-	+	+	+	-	-	-
Zanthoxylum armatum	-	-	-	-	-	-	+	+	+
Zizyphus jujuba	-	-	-	-	+	+	-	-	-
Total	4	4	5	9	9	11	6	6	6

case of shrubs, the maximum was for Seonidhar (0.827) and a minimum for Naggar (0.676).

Shannon index (H): The Shannon index for trees in the *Ulmus* growing population was maximum (2.427) for Badagram indicating that more than two tree species displayed codominance. The minimum (1.488) was for Mohal depicting that (90%) of the dominance was contributed by a single species. In the case of shrubs, the maximum was (1.988) for Dhobi and a minimum (0.342) for Babeli in *Ulmus* growing population (Table 5).

Equitability (e): Equitability for trees in *Ulmus* growing population was highest (0.962) for Pulang and lowest (0.646) for Mohal. In the case of shrubs, the maximum was for Seonidhar (0.866), and the minimum (0.728) for Naggar in the *Ulmus* growing population (Table 5).

Species richness index (Dmg): Species richness for trees in the *Ulmus* growing population was (2.589) for Badagram (Table 5), whereas a minimum (1.789) for Shamshi. In the case of shrubs, the maximum (1.791) was seen for Dhobi, while the minimum (0.488) for Babeli in *Ulmus* growing

Table 3. Importance value index (IVI) of tree and shrub species

Species	Trees								
	Kullu			Patlikuhl			Naggar		
	Shamshi	Mohal	Babeli	Badagram	Seonidhar	Dhobi	Naggar	Pulang	Rumsu
Alnus nepalensis	-	-	-	15.81	15.69	16.89	-	17.16	21.84
Cedrus deodara	-	10.36	-	23.66	23.16	42.52	-	50.24	50.9
Celtis australis	11.24	26.86	27.43	-	-	-	19.7	-	-
Eucalyptus globulus	-	-	18.05	-	-	-	-	-	-
Ficus palmata	20.62	22.43	21.01	26.91	28.91	-	16.53	24.33	21.77
Juglans regia	-	11.37	-	23.93	24.14	36.37	41.39	33.03	41.87
Melia azedarach	37.51	9.61	22.33	-	-	-	-	-	-
Melia composita	-	-	-	16.07	19.94	25.95		20.91	19.53
Morus serrata	72.38	-	10.4	21.08	21.25	10.87		22.48	18.28
Picea smithiana	-	-	-	13	16.77	16.9		19.54	22.63
Pinus wallichiana	-	-	-	40.09	43.58	56.75	38.97	39.86	32.48
Pistacia integerrima	18.82	-	10.96	-	-	-	-	-	-
Populus ciliata	-	-	-	15.36	-	-	-	-	-
Populus deltoides	-	70.74	-	-	-	-	-	-	-
Pyrus pashia	50.35	-	-	-	-	-	-	-	-
Robinia pseudocasia	-	74.94	33.62	29.76	30.21	21.84	66.95	-	-
Toona serrata	-	-	10.46	18.41	21.68	23.02	27.32	27.15	22.91
Ulmus wallichiana	89.08	73.69	145.74	55.92	54.67	48.89	89.14	45.3	47.79
Shrubs									
Berberis lycium	-	19.87	33.97	12.69	-	12.24	-	-	-
Bochmeria mivea	-	-	-	14.38	26.37	20.64	-	-	-
Daphne cannabina	-	-	-	12.25	-	13.74	39.45	54.38	54.17
Debregeasia hypoleuca	-	-	69.7	-	-	-	-	-	-
Indigofera heterantha	17.59	-	-	19.81	53.01	11.64	86.75	62.38	62.38
Prinsepia utilis	82.63	66.27	17.65	73.63	62.97	91.76	118.66	117.17	108.64
Rosa moschata	105.24	174.33	178.68	49.29	55.14	57.84	20.39	14.88	17.33
Rubus ellipticus	57.79	39.53	-	66.73	59.55	30.04	9.26	23.15	31.46
Skimmia laureola	-	-	-	34.26	17.57	25.07	-	-	
Strobilanthes glutinosus	-	-	-	16.92	10.64	25.48	-	-	-
Zanthoxylum armatum	-	-	-	-	-		25.45	21.48	26
Zizyphus jujuba	36.75	-	-	-	14.71	11.5	-	-	-

population. Recent studies have investigated the similarity and dissimilarity indices of vegetation in forest ecosystems, revealing consistent patterns in growth forms and species composition among nearby forests (Kumar and Thakur 2008; Suyal et al 2010). High similarity indices indicate the proximity and grouping of forests based on vegetation (Suyal et al 2010). Variable diversity indices (Simpson, Shannon and equitability) among tree and shrub species were also studied by Chauhan (2021), Shafi et al(2018) and Sharma et al (2020). Compared to previous studies in the Himalayas and surrounding regions have reported similar patterns. Gairola et al (2009) and Raturi (2012) stated that the species richness and diversity vary with elevation and environmental conditions. Khan et al *(*2020) indicated varied degrees of species evenness by equitability indices.

Regeneration potential: The regeneration studies were conducted for recruits (R), un-established (Un), and established (E) seedlings in the different forests of Kullu,

Table 4. Similarity and dissimilarity index of trees and shrubs in natural *Ulmus wallichiana*

S/D	Shamshi	Mohal	Babeli	Badagram	Seonidhar	Dhobi	Naggar	Pulang	Rumsu
Trees									
Shamshi	1	0.44	0.7	0.42	0.33	0.31	0.37	0.33	0.33
Mohal	0.55	1	0.37	0.22	0.11	0.22	0.13	0.11	0.11
Babeli	0.3	0.62	1	0.47	0.4	0.28	0.55	0.4	0.3
Badagram	0.57	0.77	0.52	1	0.13	0.25	0.46	0.13	0.13
Seonidhar	0.66	0.88	0.6	0.86	1	0.4	0.55	0.42	0.42
Dhobi	0.68	0.77	0.71	0.75	0.6	1	0.31	0.28	0.28
Naggar	0.63	0.87	0.45	0.54	0.45	0.69	1	0.95	0.09
Pulang	0.67	0.89	0.6	0.87	0.58	0.72	0.05	1	0.28
Rumsu	0.67	0.89	0.7	0.87	0.58	0.72	0.91	0.72	1
Shrubs									
Shamshi	1	0.5	0.28	0.5	0.75	0.62	0.66	0.33	0.33
Mohal	0.5	1	0.4	0.42	0.42	0.4	0.6	0.6	0.6
Babeli	0.72	0.6	1	0.33	0.33	0.3	0.5	0.5	0.5
Badagram	0.5	0.58	0.67	1	0.33	0.3	0.5	0.5	0.5
Seonidhar	0.25	0.58	0.67	0.67	1	0.16	0.28	0.28	0.28
Dhobi	0.38	0.6	0.7	0.7	0.84	1	0.28	0.28	0.28
Naggar	0.34	0.4	0.5	0.5	0.72	0.72	1	0.62	0.62
Pulang	0.67	0.4	0.5	0.5	0.72	0.72	0.38	1	0.45
Rumsu	0.67	0.4	0.5	0.5	0.72	0.72	0.38	0.55	1

Table 5. Diversity indices of tree and shrub species in the natural population of *Ulmus wallichiana*

Population	Diversity indices							
	Trees				Shrubs			
	Simpson	Shannon	Equitability	Species richness	Simpson	Shannon	Equitability	Species richness
Shamshi	0.722	1.585	0.762	1.789	0.736	1.793	0.799	1.227
Mohal	0.667	1.488	0.646	1.907	0.742	1.793	0.812	1.227
Babeli	0.713	1.689	0.768	2.352	0.773	0.342	0.843	0.488
Badagram	0.863	2.427	0.887	2.589	0.826	1.909	0.868	1.383
Seonidhar	0.874	2.349	0.94	2.37	0.827	1.904	0.866	1.412
Dhobi	0.872	2.184	0.915	2.245	0.805	1.988	0.829	1.791
Naggar	0.804	1.811	0.871	1.885	0.676	1.305	0.728	1.05
Pulang	0.881	2.216	0.962	2.01	0.724	1.447	0.807	1.022
Rumsu	0.87	2.208	0.941	2.118	0.751	1.549	0.864	1.079

Table 6. Regeneration status of *Ulmus wallichiana* in Kullu district of Himachal Pradesh

Sites	Populations	Recruits/ha	Unestablished regeneration/ha	Establishment regeneration/ha	Regeneration success %
Kullu	Shamshi	250	250	0	2.5
	Mohal	125	125	0	1.25
	Babeli	750	375	0	3.75
	Total	1125	750	0	7.5
Patlikuhl	Badagran	375	250	0	2.5
	Seonidhar	125	125	0	1.25
	Dhobi	250	125	0	1.25
	Total	750	500	0	5.0
Naggar	Naggar	250	128	0	1.28
	Pulang	125	125	0	1.25
	Rumsu	125	122	0	1.22
	Total	500	375	0	3.75

Patlikuhl, and Naggar Ranges of Kullu Forest division of Himachal Pradesh (Table 6). The un-established regeneration/ha of Kullu, Patlikuhl, and Naggar ranges were 750, 500, and 375 respectively. In the Kullu range, the maximum (375) number of unestablished regenerations was in Babeli and a minimum (125) in Mohal, In the Patlikuhl range, the maximum (250) number of unestablished regenerations was in Badagram and a minimum (125) in Seonidhar and Dhobi whereas in the Naggar range maximum (128) number of unestablished regenerations in Naggar and minimum (122) in Rumsu.

The regeneration success percentages of Kullu, Patlikuhl, and Naggar ranges were 7.50, 5.00, and 3.75 respectively. In Kullu range the maximum (3.75%) of regeneration success was in Babeli and the minimum (1.25%) in Mohal, In the Patlikuhl range maximum (2.50%) of regeneration success was in Badagram and the minimum (1.25%) in Seonidhar and Dhobi and Naggar range maximum (1.28%) of regeneration success in Naggar and minimum (1.22%) in Rumsu. In all the populations, the established regeneration recorded was nil. The overall number of recruits/ha in Kullu, Patlikuhl, and Naggar was 1125,750, and 500 respectively (Table 6). In the Kullu range the maximum (750) number of recruits were in Babeli and a minimum (125) of recruits were found in Mohal followed by Patlikuhl and the Naggar range.

The *Ulmus* forest exhibited a decreasing trend of regeneration success with altitudinal ranges: Kullu>Patlikuhl> Naggar. The Kullu range (1100-1500) had the highest regeneration success of *Ulmus wallichiana* (7.5), whereas the Naggar range (1800-2100) had the lowest regeneration success of *U. wallichiana* (3.75). Maximum regeneration was recorded at lower altitudes.

CONCLUSIONS

The phytosociological analysis of *Ulmus wallichiana* in the Kullu range revealed significant findings regarding its floristic composition and diversity patterns. The study identified Badagram and Dhobi sites in the Patlikuhl range as hotspots for tree and shrub diversity, with *U. wallichiana* emerging as the dominating species at Babeli site, followed by *Robinia pseudocasia* and *Populus deltoides* at Mohal site. Conversely, *Morus serrata* exhibited the lowest dominance at the Babeli site. The species richness declined with increasing elevation, while natural regeneration of *U. wallichiana* peaked (7.5%) at lower altitudes (1100-1500m) and dwindled at higher altitudes (1800-2100). Given *U. wallichiana's* vulnerable status, these findings underscore the imperative for immediate in-situ and ex-situ conservation efforts to protect this species and its habitats, particularly in lower elevation ranges where regeneration is optimal.

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Variation in Physico- Chemical Properties of (*Diospyros montana* Roxb.) in Himachal Pradesh

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Abstract: The present study was confined to 19 mother trees of *Diospyros montana* Roxb. distributed in Solan districts of Himachal Pradesh. Mother trees were selected from Nalagarh and Baddi area of Solan district. Physico- chemical properties were studied by collected wood samples from the 19 mother trees. Specific gravity was recorded maximum for mother trees 7 and 2 (M_7andM_2) of Nalagarh area, fiber length and fiber diameter was recorded maximum for mother trees 8 and 19 (M_8 and M_{19}) and holocellulose content was maximum for mother tree 15 (M_{15}) of Baddi area. Maximum moisture Content (MMC) showed significant correlation with specific gravity and alcohol- benzene extractives. Fiber length is correlated with fiber diameter. 89.88% of variation was showed by five PCA for wood parameters.

Keywords: Variation, Diospyros, Repeatability, PC clusters, Correlation

India is blessed with a wide range of vegetation types, from tropical to subtropical, temperate to subalpine, and alpine. Within an ecosystem, forests play both a protective and productive role. The protective role of the forest is limited to the production of timber, but it also produces non-timber forest products, which are derived from over 3,000 species. Non-timber forest products (NTFPs) are biological products other than timber that are harvested by humans from wild biodiversity in both natural and artificial environments (Sardeshpande and Shackleton 2019). Due to inadequate understanding of their intended uses, many products are either not fully extracted or are thrown away. Most species have had little research done on their biodiversity. but plants or their products are traded, even their identification and classification are sometimes inadequate, creating significant confusion. *Diospyros montana* (family Ebenaceae), commonly known as Bombay ebony found in some parts of Solan, Sirmour and Una district. It is a small deciduous tree upto 20 m high with spiny trunk and branches. It is a dioecious (separate male and female plants) tree species. It is commonly known as ebony tree because of its hard, heavy and dark timber. The wood of *Diospyros* isgrey, often tinged with yellow or brown, streaked with narrow patches of darker colour, especially towards the centre, but there is no regular ebony heartwood. The wood is soft to moderately hard and durable

Theplant populations in the wild display complicated patterns of diversity, which makes it essential to choose superior stands for breeding (Gupta and Sehgal 2000). Variability in important traits is critical to the evolution of a species. For a species to adapt and become better through breeding programs, variations are necessary. Tree breeding cannot raise the quality if there is no variation in the trees. Determining the amount, source, and kind of variation present in the target species is the first step in any improvement endeavor. Three characteristics set trees apart: their varied surroundings, their individual peculiarities, and the way their genotype interacts with their growing environment. The study was conducted to observe the variation in physico- chemical properties of *Diospyros montana* Roxb.

MATERIAL AND METHODS

Keeping in view the importance of wood of *diospyros* samples were collected from 19 mother trees selected in Nalagarh and Baddi area of Solan district of Himachal Pradesh (Table 1). After collection, drying and sawing of wood samples the following physical, anatomical and chemical wood properties were recorded. Bark percent was calculated as D.O.B.- D.U.B./ D.O.B.*100. D.O.B = Diameter over bark and D.U.B = Diameter under Bark. Wood percent was calculated as D.O.B.- 2*bark thickness/ D.O.B.)*100. The moisture per cent of the samples was calculated by using method given by Desch and Dinwoodie (1996) i.e. Mi_{ni}-M_{od}/ M_{od}*100.

Mi_{ni} is initial weight of samples (g) and M_{od} is oven dried weight of samples (g). Maximum moisture content (MMC) of wood samples were determined (BIS 1986) i.e. Mm- Mo/ Mo*100, where, Mm is Saturated weight of wood samples (g). The specific gravity of the samples were determined by maximum moisture content method (Smith 1954) -

$$= \frac{1}{\frac{Mm - Mo}{Mo} + \frac{1}{GS}}$$

Where,

Mm = Fresh weight of the sample

Mo = Oven dried constant weight of sample.

GS = Average density of wood substance a constant having value 1.53.

The fiber dimensions were determined by macerating the wood shavings in Jeffery's solution, i.e. 10 per cent chromic acid and 10 per cent nitric acid, for 48 hours (Pandeya et al 1968). The cold and hot water soluble extractives were determined by employing the T1m 59 methods (Anonymous 1959a). Alcohol benzene extractives, Kalson-lignin content and holocellulose were determined by using the T6m 59 (Anonymous 1959b), T12m 59 (Anonymous 1959c) and T9m 54(Anonymous 1959d) methods respectively. The experimental data of all the tree characters studied were subjected to the statistical analysis for proper interpretation. The data was analyzed statistically using Random Nested Model as follows:

= μ + + +

Where:

μ = grand mean, p_i = effect of ith natural population (i=1,2.....p) m $(p)_{j(i)}$ = the jth mother tree effect within each ith natural population e_{ijk} = the interaction of the kth observation and jth mother tree in the ith natural population

Repeatability

Genotype repeatability =

Where, = Genotype variance, = Within genotype variance

Heritability in percentage was calculated as suggested by Burton and De-Vane (1953) and Johnson et al (1955). The expected genetic advance at 5 per cent selection intensity was calculated as suggested by Lush (1940) and further used by Burton and De-Vane (1953) and Johnson et al (1955). Genetic gain was worked out following the method suggested by Johnson et al(1955). Correlations were computed to examine inter-character relationships among different wood parameters .Principal component and cluster analysis were investigated by principal component analysis (PCA). PCA was performed using JMP pro 10software. Cluster analysis was also performed to cluster genotypes into similarity groups using the method of UPGA (Unweighted Pair Group Average) using ward method (Ward 1963).

RESULTS AND DISCUSSION

In physical properties of wood mother tree 11(M_{11})from Baddi showed the maximum wood percent (WP) of 97.14% and minimum (88.68 %) was for M_2 (Table 2). Maximum bark percent (BP) was for M_2 (11.32%) and minimum (2.86%) was recorded for M_{11}. M_2 showed the highest moisture content (MC) (81.92%) where and lowest (32.29%) moisture content (MC) was for M_1. The highest maximum moisture content (MMC) of 163.84% was observed for M_2 and lowest (64.58) maximum moisture content was for M_1. However specific

Table 1. Physical description of mother trees

Sites	Mother trees	Mother trees code	Altitude (feet)	Latitude (n)	Longitude (e)
Nalagarh	1	M_1	1207	30°59'909"	76°44'713"
	2	M_2	1202	30°59'915"	76°44'710"
	3	M_3	1205	30°59'917"	76°44'712"
	4	M_4	1201	30°59'867"	76°44'660"
	5	M_5	1204	30°59'867"	76°44'655"
	6	M_6	1200	30°59'881"	76°44'646"
	7	M_7	1203	30°59'935"	76°44'742"
	8	M_8	1202	30°59'984"	76°44'778"
	9	M_9	1209	30°59'939"	76°44'762"
Baddi	10	M_{10}	1597	30°59'694"	76°44'634"
	11	M_{11}	1673	30°59'460"	76°44'625"
	12	M_{12}	1719	30°59'472"	76°44'769"
	13	M_{13}	1760	30°59'493"	76°44'965"
	14	M_{14}	1764	30°59'505"	76°44'978
	15	M_{15}	1775	30°59'509"	76°44'019"
	16	M_{16}	1859	30°59'668"	76°44'075"
	17	M_{17}	1859	30°59'673"	76°44'076"
	18	M_{18}	1862	30°59'675"	76°44'079"
	19	M_{19}	1869	30°59'680"	76°44'085"

gravity was maximum (0.81) for M_7 and minimum (0.44) for M_2.Maximum fiber length (0.71mm) was recorded for M_8 which was followed by M_{10}(0.70mm) and minimum (0.58mm) for M_{11}. Maximum and minimum fiber diameter was for M_{19} (13.82µm) and M_7(11.54 µm). Cold water-soluble extractives were maximum in M_2 and hot water-soluble extractives were by mother tree 16 (M_{16}). Mother tree 8 (M_8) of Nalagarh area showed maximum alcohol-benzene content.Maximum holocellulose and lignin content was by M_{15} and M_{13} of Baddi area.

The value of phenotypic coefficient of variation (55.11%) and genotypic coefficient of variation (33.02%) were maximum for bark percent (BP) and minimum for wood percent (WP) i.e., 4.40% and 2.63%, respectively. Repeatability coefficient was maximum (0.75) for fiber length and minimum for cold water solubility (Table 3). The genetic variance between and within populations was not measured accurately because genetic effects can't be isolated from environmental effects in natural populations when parental origin and environmental influences cannot be controlled. As a result, were unable to calculate the heritability coefficient at the population or individual tree level. In this case, use the repeatability coefficient, which may be considered as the top limit of the genetic-phenotypic variance relationship (Falconer and Mackey 1996). These coefficients also show the proportion of within-population variation that contributes to total variance and the proportion of between-tree variation that contributes to total population variation.

However, genetic gain percent was maximum (44.68%) for moisture content (MC) and minimum (3.25%) for wood percent. For the proper utilization of observed variation in a species, it is prerequisite to know the extent of variation and also that whether, it is due to the genetic or the environmental factors. Hence, information on variation in the desired parameters and their correlation is vital for any breeding programme .

Wood percent showed highly significant negative correlation with bark percent (-1.00). Bark percent showed negative correlation with hot water solubility (-0.46). Moisture content showed significant correlation with (MCC) maximum moisture content (1.00%), negative correlation with specific gravity. Hollcellulose content was highly significant and negative correlated with lignin content .Bisen et al (2018) observed that in *Cleistanthus collinus* (Roxb.), bark percent

Table 2. Variation in different wood properties

Mother trees	Wood percent (WP)	Bark percent (BP)	Moisture content (%) (MC)	Maximum moisture content (%) (MCC)	Specific gravity	Fiber length (mm)	Fiber diameter (µm)	Cold water soluble extractives (%)	Hot water soluble extractives (%)	Alcohol-benzene extractives (%)	Holocellulose content (%)	Lignin content (%)
M_1	91.21	8.79	32.29	64.58	0.77	0.64	12.18	7.63	8.25	9.30	77.50	13.2
M_2	88.68	11.32	81.92	163.84	0.44	0.64	11.97	9.00	5.75	7.00	72.00	21
M_3	89.47	10.53	45.31	90.62	0.65	0.59	11.76	7.46	6.58	6.43	74.17	19.4
M_4	96.87	3.13	62.59	125.17	0.53	0.59	12.04	5.96	9.00	7.87	71.75	20.38
M_5	95.41	4.59	32.49	64.99	0.66	0.60	11.97	8.71	8.17	6.87	77.25	15.88
M_6	89.63	10.37	31.56	63.11	0.73	0.69	13.04	6.87	8.67	9.27	77.42	13.31
M_7	92.38	7.62	27.83	55.66	0.81	0.65	11.54	8.37	5.33	8.73	76.33	14.94
M_8	93.41	6.59	48.09	96.17	0.67	0.71	12.11	7.04	10.08	9.50	68.50	22
M_9	89.40	10.60	33.44	66.89	0.77	0.69	12.47	7.58	9.50	8.23	79.17	12.6
M_{10}	95.77	4.23	47.47	94.94	0.63	0.70	13.11	6.12	8.42	7.53	80.42	12.05
M_{11}	97.14	2.86	37.16	74.33	0.73	0.58	13.18	6.92	7.50	6.47	79.67	13.86
M_{12}	92.03	7.97	69.05	138.11	0.50	0.66	12.68	6.50	7.25	6.87	56.58	36.55
M_{13}	89.03	10.97	47.95	95.90	0.63	0.68	13.11	6.42	5.67	6.10	63.83	30.07
M_{14}	94.80	5.20	54.89	109.78	0.57	0.67	12.11	6.88	8.50	7.80	81.92	10.28
M_{15}	89.24	10.76	64.36	128.72	0.52	0.63	13.25	7.83	6.08	7.37	85.33	7.3
M_{16}	95.86	4.14	56.98	113.97	0.56	0.69	12.47	6.92	10.67	7.73	78.67	13.6
M_{17}	96.82	3.18	40.87	81.74	0.68	0.62	12.61	6.54	9.17	6.77	69.33	23.9
M_{18}	92.97	7.03	48.91	97.83	0.63	0.67	12.61	8.62	8.75	7.80	69.50	22.7
M_{19}	89.54	10.46	52.66	105.33	0.59	0.67	13.82	8.62	8.92	6.80	72.58	20.62
CD (p=0.05)	5.37	5.37	16.89	34.12	0.12	0.03	1.12	2.35	2.42	1.79	11.93	12.24

was negatively correlated with hot water solubility and holocellulose content. Fiber length showed significant correlation with alcohol- benzene soluble extractives. Fiber width is negative correlated with alcohol- benzene soluble extractives (Table 4). Cold water-soluble extractives are negatively correlated with hot water-soluble extractives and hot water-soluble extractives showed positive correlation with alcohol-benzene soluble extractives. Alcohol benzene soluble extractives showed negative correlation with lignin content.

Total 89.88% variation was showed by first five components (Table 5). The first component explained 31.09% variation in moisture, maximum moisture content (0.89) and lignin content (0.63). The second component explained 20.98% of variation in which maximum was showed for bark percent (0.91), specific gravity (0.25) and cold-water solubility (0.62). 14.39% variation was showed by third component in which maximum was exhibited for fiber length (0.81), fiber diameter (0.28) and hot water solubility (0.47). The fourth component explained 13.56% of variation showed by holocellulose content. The fifth component explained maximum variation for alcohol- benzene

Table 3. Variability estimates, genetic parameters and repeatability coefficient of wood parameters

Parameters	Phenotypic coefficient of variation	Genotypic coefficient of variation	Repeatability coefficient	Genetic advance	Genetic gain (%)
Bark percent (BP)	55.11	33.02	0.36	3.01	40.75
Wood percent (WP)	4.40	2.63	0.36	3.01	3.25
Moisture content (MC)	34.70	27.43	0.63	21.54	44.68
Maximummoisture content (MCC)	34.70	27.43	0.63	43.07	44.68
Specific gravity	18.25	14.53	0.63	0.15	23.83
Fiber length	6.75	3.36	0.75	0.07	10.45
Fiber diameter	6.44	3.71	0.33	0.55	4.42
Cold water soluble extractives	20.28	6.13	0.09	0.28	3.82
Hot water soluble extractives	24.29	16.03	0.44	1.75	21.80
Alcohol- benzene extractives	17.78	10.67	0.36	1.00	13.20
Holocellulose content	12.15	7.29	0.36	6.70	9.02
Lignin content	51.85	31.64	0.37	7.19	39.77

Table 4. Estimation of correlation coefficients among different wood properties

Parameters	Wood (%)	Bark (%)	Moisture content (%)	Maximum moisture content (%)	Specific gravity	Fiber length	Fiber width	Cold water soluble extractives	Hot water soluble extractives	Alcohol- benzene soluble extractives	Holocellulose content	Lignin Content
Wood percent	1.00											
Barkpercent	-1.00**	1.00										
Moisture content	-0.13	0.13	1.00									
Maximum moisture content	-0.13	0.13	1.00**	1.00								
Specific gravity	0.05	-0.05	-0.96**	-0.96**	1.00							
Fiber length	-0.25	0.25	0.01	0.01	0.05	1.00						
Fiber width	-0.14	0.14	0.08	0.08	-0.12	0.25	1.00					
Cold water soluble extractives	-0.42*	0.42	-0.02	-0.02	0.03	-0.10	-0.17	1.00				
Hot water soluble extractives	0.46	-0.46*	-0.15	-0.15	0.10	0.34	0.10	-0.27	1.00			
Alcohol- benzene soluble extractives	-0.03	0.03	-0.34	-0.34	0.43	0.45	-0.30	0.01	0.37	1.00		
Holocellulose content	0.11	-0.11	-0.29	-0.29	0.25	-0.09	0.02	0.16	0.09	0.24	1.00	
Lignin content	-0.10	0.10	0.32	0.32	-0.30	0.02	0.02	-0.16	-0.14	-0.37	-0.99**	1.00

Table 5. Principal component analysis

Parameters	PC1	PC2	PC3	PC4	PC5
Bark percent	0.33	0.91	0.16	0.03	-0.05
Wood percent	-0.33	-0.91	-0.16	-0.03	0.05
Moisture content	0.89	-0.17	-0.07	0.38	0.15
Maximum moisture content	0.89	-0.17	-0.07	0.38	0.15
Specific gravity	-0.86	0.25	0.13	-0.38	-0.07
Fiber length	-0.05	0.2	0.81	0.39	0.03
Fiber diameter	0.16	0.02	0.28	0.23	-0.88
Cold water-soluble extractives	0.04	0.62	-0.35	0.05	0.24
Hot water-soluble extractives	-0.37	-0.5	0.47	0.35	0.07
Alcohol- benzene extractives	-0.56	0.18	0.4	0.32	0.51
Holocellulose content	-0.57	0.13	-0.49	0.61	-0.16
Lignin content	0.63	-0.15	0.41	-0.63	0.08
Eigen value (%)	3.73	2.52	1.73	1.63	1.18
Percent of variance	31.09	20.98	14.39	13.56	9.86
Cumulative percent	31.09	52.08	66.47	80.03	89.88

Table 6. Cluster analysis

Cluster	1	2	3
No. of mother trees in cluster count	5	8	6
Notation of trees	M_1, M_3, M_6, M_7,M_9	M_4, M_5,M_8, M_{10}, M_{11}, M_{14}, M_{16}, M_{17}	M_2, M_{12}, M_{13}, M_{15}, M_{18}, M_{19}
Bark percent	9.58	4.24	9.75
Wood percent	90.42	95.76	90.25
Moisture content	34.09	47.57	60.81
Maximum moisture content	68.17	95.14	121.62
Specific gravity	0.75	0.63	0.55
Fiber length	0.65	0.65	0.66
Fiber diameter	12.2	12.45	12.91
Cold water-soluble extractives	7.58	6.89	7.83
Hot water-soluble extractives	7.67	8.94	7.07
Alcohol- benzene soluble extractive	8.39	7.57	6.99
Holocellulose content	76.92	75.94	69.97
Lignin content	14.69	16.49	23.04

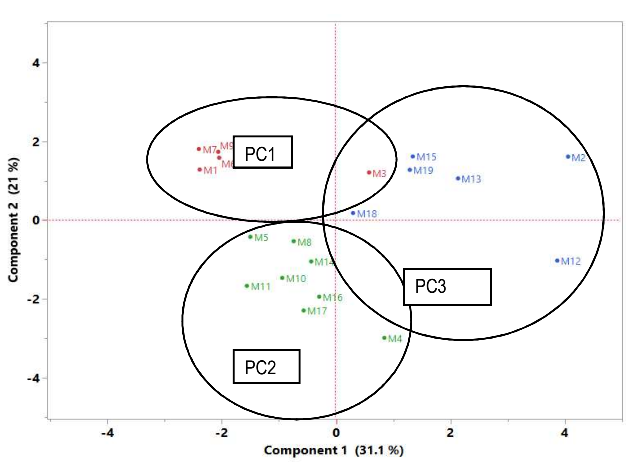

Fig. 1. Scatter plot diagram of PC1- PC2 for wood traits

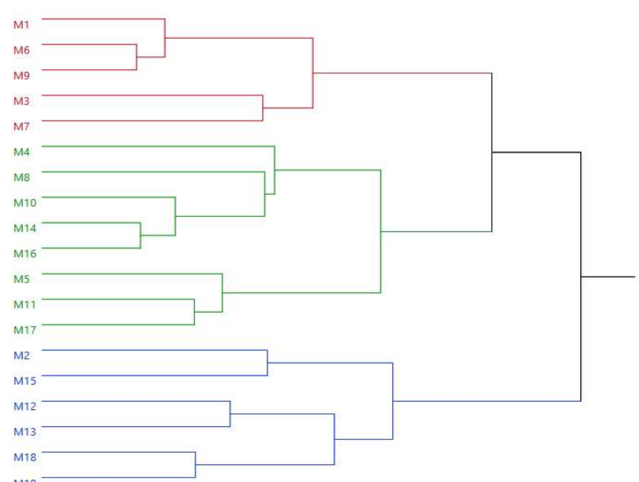

Fig. 2. Dendrogram showing clusters for wood traits

extractives. The highest amount of variance is justified by the first component and the remaining variances are justified by the subsequent components (Khadivi Khub and Khalili 2017).

Cluster I contained highest mean value for specific gravity (0.75), alcohol- benzene extractives (8.39) and holocellulose content (76.92). Cluster II contained maximum value for wood percent (95.76) and hot water solubility (8.94). Cluster III contained maximum values for moisture content (60.81), maximum moisture content (MMC) 121.62, fiber length (0.66) and fiber diameter 12.91 (Table 6).

CONCLUSION

Mother trees M_1 and $M_7$from Nalagarh have better strength properties (specific gravity) therefore, can be considered best with desirable timber qualities for furniture and musical instruments especially finger boards and keys of guitars and desks because of specific gravity. Mother trees with fiber parameters and holocellulose content can be used for paper and pulp making.

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Dynamics of Soil Physical and Chemical Properties under Fruit Tree based Agroforestry Systems in Sub-humid Agro-climatic Zone

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Abstract: The dynamics of soil physical and chemical properties under different fruit tree based agroforestry systems and in open conditions was observed during two consecutive years 2020-2021. The physical and chemical properties of soil were favourably affected by systems. Soil moisture (9.75%) was maximum under pear based agroforestry system and minimum under open conditions. The chemical properties viz., soil available nitrogen (268.37 Kg ha^{-1}), soil available potassium (269.42 Kg ha^{-1}), soil available phosphorus (39.16 Kg ha^{-1}), soil pH (7.06), soil organic carbon (1.30%) were maximum in pear based agroforestry system and minimum under open conditions. Soil electrical conductivity (0.21 dSm^{-1}) was also more under pear based agroforestry system as compared to open system.

Keywords: Agroforestry systems, Soil organic carbon, Soil pH

Soil is a component of lithosphere and biosphere system . It is a vast natural resource on which life supporting systems and socioeconomic development depends. Organic matter is one of the most important constituents of soil, a good amount of organic carbon/matter increase soil fertility. The core constraints in relation to land use include depletion of organic carbon, soil macronutrients and micronutrients. (Kumar et al 2017). Potential land use assessment is likely to the prediction of land potential for productive land use type (Dadhwal et al 2011) land productivity capacity or land quality is a comprehension, at the same time a precise concept in terms of agricultural activities (Dengiz and Saglam 2012).

Forests and tree based systems can play a crucial role in supplementing agricultural production to provide better and more equitable nutrients for cooking (Vinceti et al 2013). Food sustainability in all its facets, in an environment at risk of breaching global limits through its human exploitation and alteration of nature, atmosphere, water and nutrient cycles (Rockstorm et al 2009). Climate-Smart Agroforestry (CSA) seeks to contribute to adaptation and tolerance of climate change in agricultural systems, while also contributing to mitigation (reduction of emissions) and food protection (Campbell et al 2014, World Bank 2016). Fruit tree based agroforestry system is highly popular among resource limited producers worldwide due to its relative pre-production phase of fruit trees, the high market value of their products. Many fruit tree species have been identified to have tolerance to sodic soils and other soil related constraints (Pandey 2019).

The present production system has endangered health and environmental security due to abundant use of chemical fertilizers and pesticides. Eminent position in global cultivation of wheat, pulses, vegetables and fruits etc. is occupied by Indian agriculture and reason of physical, chemical condition of whatever land is indispensable for proper implementation of the other management practices. Thus the physico-chemical study is very important because both physical and chemical properties which bear upon the soil productivity. The physico chemical study of soil is based on variousparameters like pH, EC, moisture, available nitrogen, phosphorus and potassium (Kekane et al 2015). Maintenance or enhancement of soil quality is a more important criterion for analysis and sustainability of soil ecosystems. The effect of combined plantation of selective fruit species for improvement of poor fertile soils has not been worked out so far. This study assessed the performance of two fruit tree based agroforestry systems in order to obtain knowledge on sustainable farming system for the region.

MATERIAL AND METHODS

Experiment was conducted at Dr. YSP University of Horticulture and Forestry, Nauni, Solan (H P). The experimental site falls in mid hill zone of Himachal Pradesh at $30^0 51'$ N latitude and 76^0 11' E longitude, with an elevation of 1200 m amsl. The area falls in sub-tropical, sub-humid agro-climatic zone of Himachal Pradesh, India. May and June are the hottest months, whereas December and January are the coldest months and experience severe frost during winter. On an average the annual rainfall received varies from 1000-1400 mm; about 75 per cent being received during the monsoon period (June-September). The soils of the area belongs to Typic Eutrochrept at subgroup level according to Soil Taxonomy of USDA.

The experiment was in randomized block design and treatment combinations include 2 (Tree components: apricot and pear), 2 planting condition (Inside and outside canopy), 3 varieties (Kranti, P-8, and Tender), 3 nutrient and fertilizer doses (RDF (75:50:50 NPK Kg ha^{-1} + FYM @15 t ha^{-1}), Jeevamrut (500 litres ha^{-1}) and FYM (15 t ha^{-1}). Open plots was an area where different okra varieties without trees (pear and apricot), and was established in close proximity to agroforestry systems. Okra varieties were sown at a spacing of 45 x 15 cm. The height, girth of trees and crown spread (m^2) was measured during 2020-2021. Light Transmission Ratio of two systems pear and apricot was taken with the help of luxmeter. Fruit yield of tree was recorded during the two respective years (2020-2021).

Statistical analysis: IBMSPSS Statistics software was used for analysis.

Soil analysis: For soil analysis, viz., soil moisture, pH, EC, organic carbon, available N, P and K. composite soil samples were collected from 0-15cm depth from each plot, before sowing and after harvesting of crops. The pH and electrical conductivity of soil were determined by using 1:2.5 soil: water suspension (Jackson 1973). Organic carbon, available nitrogen and available phosphorus were determined by using rapid titration method (Walkley and Black 1934) and Olsen et al (1954), respectively. Available potassium was estimated using neutral 1 N ammonium acetate solution (Merwin and Peech 1951).

RESULTS AND DISCUSSION

Soil chemical properties

Soil organic carbon (%): The maximum soil organic carbon (1.30%) was in pear based agroforestry system followed by apricot based agroforestry system and minimum (1.24%) under open conditions. Olsson et al (2000) also reported higher soil moisture content under *Millettia ferruginea* as compared to outside the tree. Gupta et al (2009) observed that soil organic carbon increased from 0.36% in sole crop to 0.66% in agroforestry soils. The varieties revealed non-significant differences with respect to soil organic carbon. The maximum soil organic carbon was in FYM when applied FYM@15 t ha^{-1}(1.32%) and minimum (1.24%) with the application of NPK: 75: 50: 50 Kg ha^{-1} + FYM 15 t ha^{-1} (Table 1).

Soil available nitrogen (Kg ha^{-1}): The soil available nitrogen was maximum in pear based agroforestry system (268.37 Kg ha^{-1}) followed by apricot based agroforestry system and minimum under open conditions (216.74 Kg ha^{-1}). Mishra et al (2006) also observed increase in soil nitrogen under tree cover. Tripathi (2012) made a similar conclusion and reported significantly higher levels of available soil nitrogen under tree (peach) cover than in open condition which may be due to repeated addition of litterfall to the soil. Atta et al (2013) observed higher available nitrogen under tree canopy of *Acacia* species as compared to outside the tree canopy. This was due to immobilization of nutrients by microbes which

Table 1. Effect of systems, varieties and fertilizers on soil chemical properties under *Abelmoschus esculentus*

Treatments	Soil organic carbon (%)	Soil available nitrogen (kg ha^{-1})	Soil pH	Electrical conductivity (dSm^{-1})	Soil moisture (%)	Soil available potassium (kg ha^{-1})	Soil available phosphorus (kg ha^{-1})
Systems							
Apricot (S_A)	1.28	248.24	7.06	0.19	7.05	265.02	36.87
Pear (Sp)	1.30	268.37	6.79	0.21	9.75	269.42	39.16
Open (S_O)	1.24	216.74	6.40	0.17	6.55	230.52	33.50
CD (p=0.05)	0.02	26.83	0.35	0.01	0.40	15.19	2.24
Varieties							
Kranti (V_1)	1.27	232.64	7.25	0.19	6.58	245.08	35.61
P-8 (V_2)	1.26	256.81	6.54	0.19	8.43	261.27	36.32
Tender (V_3)	1.29	243.89	6.46	0.19	8.35	258.60	37.60
CD (p=0.05)	NS	NS	0.35	NS	0.40	NS	NS
Fertilizers							
RDF+ FYM (F_1)	1.24	277.42	6.59	0.17	7.88	279.27	39.71
Jeevamrut (F_2)	1.27	244.27	6.38	0.20	7.56	258.78	36.44
FYM (F_3)	1.32	211.67	7.27	0.20	7.91	226.90	33.40
CD (p=0.05)	0.02	26.83	0.35	0.01	NS	15.19	2.24

when biologically transformed becomes available to plant. Varieties revealed non-significant differences with respect to soil nitrogen. Soil nitrogen was maximum in F_1 (RDF + FYM) (277.42 Kg ha^{-1}) and minimum in F_3(211.67 Kg ha^{-1}) (Table 1).

Soil pH: Soil pH was maximum in apricot based agroforestry system (7.06) followed by pear based agroforestry system and minimum under open conditions (6.40). Akter et al (2020) in jackfruit turmeric based agroforestry observed maximum soil pH (4.75) in tree based agroforestry system as compared to sole cropping (4.72). Uthappa et al (2015) reported that soil physico-chemical properties influenced by varying tree densities in poplar based agroforestry system and soil pH in 0-15 cm layer was maximum (8.36) at tree density of 500 trees/ha as compared to minimum in sole crop (8.33).Varieties revealed that maximum soil pH was after harvesting of Kranti (7.25) and minimum in Tender variety (6.46). Among different fertilizer doses, maximum soil pH was in FYM (7.27) and minimum in Jeevamrut (6.38) (Table 1).

Electrical conductivity (d sm^{-1}): Electrical conductivity was maximum in pear based agroforestry system (0.21d sm^{-1}) during both the years. Varieties revealed non-significant result with respect to EC. Among fertilizers, maximum EC (0.21d sm^{-1}) was in treatment of jeevamrut and minimum (0.17 d sm^{-1}) in RDF+FYM (Table 1).

Soil moisture: Soil moisture was maximum (9.75%) in pear based agroforestry system and minimum (6.55%) under open conditions. Among three varieties of *Abelmoschus esculentus* (soil moisture was maximum (8.43%) in P-8 variety and minimum in Kranti (6.58%). Rahman et al (2018) also observed maximum (12.07%) soil moisture in agroforestry system and minimum (10.37%) under open conditions. This was due to increase in water infiltration and reduced surface runoff. Different fertilizers usage revealed non-significant result for soil moisture during (Table 1).

Soil available potassium (Kg ha^{-1}): The maximum soil available potassium was in pear based agroforestry system (269.42 Kg ha^{-1}) followed by apricot based agroforestry system and minimum under open conditions (Table 1). Uthappa et al (2015) in varying tree densities in poplar based agroforestry system found that available potassium (K) was greatly influenced by tree densities. Maximum available potassium in 0-15 cm layer was at tree density of 1000 trees/ha (228.11 kg ha^{-1}). Among different fertilizers, maximum potassium availability (279.27 kg ha^{-1}) was in RDF +FYM and minimum (226.90 kg ha^{-1}) with F_3. Varieties revealed non-significant result with respect to soil available potassium.

Soil available phosphorus (Kg ha^{-1}): The maximum soil available phosphorus was in pear based agroforestry system (39.16 kg ha^{-1}) followed by apricot based agroforestry system (and minimum (33.50 kg ha^{-1}) under open conditions. Manjur et al. (2014) reported that available phosphorus was higher under canopies of *Faidherbia albida* and *Croton macrostachys* tree species and all showed decreasing trend with increasing distance from tree base which was attributed to high accumulation of organic matter under tree canopies. Gulabrao (2016) made a similar conclusion and recorded that available phosphorus was higher where plants were grown under trees and supplied with higher doses of organic manures. Among fertilizers, maximum (39.71 kg ha^{-1}) was in F_1 (75:50:50 NPK kg ha^{-1} + FYM @15 t ha^{-1}) and minimum (33.40) in F_3 (FYM @ 15 t ha^{-1}.

Effect of systems, varieties and fertilizers on yield of *Abelmoschus esculentus*: The systems, varieties and fertilizers showed significant effect on number of fruits per plant. Among systems, maximum number of fruits per plant (11.53) were in open system followed by pear based agroforestry system and minimum (10.07) under apricot based system. The maximum number of fruits (11.51) per plant were in P-8 variety which was at par with Tender and minimum (10.06) in Kranti variety. However, different fertilizer doses revealed that the maximum number of fruits per plant (11.69) were in RDF+ FYM, followed by jeevamrut (11.00) and minimum (9.98) in FYM (Table 2). The maximum fruit yield plot^{-1} (1.64 kg), was in open system, followed by pear based agroforestry system (1.55 kg) and minimum (1.44 kg)

Table 2. Effect of systems, varieties and fertilizers on no. of fruits per plant, fruit yield and yield of *Abelmoschus esculentus*

Treatments	No of fruits per plant	Fruit yield plot^{-1} (kg)	Yield (q ha^{-1})
Systems			
Apricot (S_A)	10.07	1.44	72.38
Pear (S_P)	11.05	1.55	77.63
Open (S_O)	11.53	1.64	83.25
CD (p=0.05)	0.43	0.07	3.82
Varieties			
Kranti (V_1)	10.06	1.42	71.46
P-8(V_2)	11.51	1.62	82.10
Tender (V_3)	11.09	1.58	79.69
CD (p=0.05)	0.43	0.07	3.82
Fertilizers			
RDF+ FYM (F_1)	11.69	1.70	85.11
Jeevamrut (F_2)	11.00	1.55	78.42
FYM (F_3)	9.98	1.38	69.72
CD (p=0.05)	0.43	0.07	3.82

in apricot based agroforestry system. The maximum fruit yield (83.25 q ha^{-1}) was in open system followed by pear based agroforestry system and minimum under apricot based system. Among varieties, the maximum fruit yield $plot^{-1}$ (1.62 kg) was in P-8 variety which was at par with Tender and minimum (1.42 kg) was recorded in Kranti variety. The maximum (1.70 kg) fruit yield $plot^{-1}$ was in RDF + FYM followed by jeevamrut and minimum (1.38 kg) in FYM.

The maximum fruit yield (83.25 q ha^{-1}) was in open system followed by pear based agroforestry system and minimum (72.38 q ha^{-1}) under apricot based system. Among varieties, the maximum fruit yield (82.10 q ha^{-1}) was in P-8 variety which was at par with Tender and minimum (71.46 q ha^{-1}) was in Kranti variety. The different fertilizer doses revealed that the maximum fruit yield (85.11 q ha^{-1})was in RDF+ FYM, followed by jeevamrut and minimum in FYM (Table 2).

CONCLUSION

The physical and chemical properties of soil were favorably affected with in agroforestry system. Most of the soil physical and chemical properties were found more under apricot tree based agroforestry system as compared to open conditions. The present study revealed the effect of different fruit tree species on soil physico chemical properties in the same area. However, more intensive studies are required in different agroecological regions for reliability and better acceptance.

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Carbon-Sequestration Potential of Bamboo-based Farming Systems in Peri-Urban Landscapes

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***Abstract*:** The study is built upon the importance of bamboo as a component in the land-use in the peri-urban areas of Tripura West, Tripura as this area is known for bamboo in their homestead along with cultivation of crops. The study accounted bamboos as woody components in the land-use and estimated the carbon sequestration along with other woody tree components in the system. The total emission from crops was 100,086.53kg CO_2e, while the sequestration by woody species of trees and bamboos was 362629.68 kg CO_2e which ultimately gave net positive carbon emission value of 262543.15 kg CO_2e. The highest emitter was lowland rice (4454.87 kg CO_2e/ha) and the highest sequestration potential was seen in *Bambusa tulda* (48030.89 kg CO_2e/ha).

***Keywords*:** Agriculture Land-use, Bamboo-based Agroforestry, Climate change, Emissions, Mitigation

Agriculture is responsible for fifty percent of the earth's methane and nitrous oxide emission having more global warming potentials 28 and 265 times more than carbon-di-oxide respectively (Carlson et al 2016, IPCC 2018). The main challenge is overcoming growing food needs due to growing population, while minimizing the bad environmental impact of agriculture especially GHGs emission (Pathak et al 2014, Sapkota et al 2015, Ram et al 2016, Vetter et al 2019). Estimating greenhouse gas emissions from agriculture and allied activities is crucial for evolving mitigation strategies (Carlson et al 2016, Jat et al 2016, Kim et al 2016, Fagodiya et al 2017, Fagodiya et al 2020, Barreto et al 2024). The main elements of reducing carbon stocks and increasing amount of greenhouse gas in the environment are forest conversion, land-use changes and various agricultural practices (Hergoualc'h et al 2012, Luedeling et al 2014, Sharma et al 2016, Ajit et al 2013, Ajit et al 2017). Agroforestry can play the role (Jose and Bardhan 2012, Thangata and Hildebrand 2012, Majumdar et al 2013) by adopting ethnic community based traditional techniques in agriculture that uses less machinery and input of FYM and tilling modifications in place of fertilizers (Selvan and Kumar 2016). Bamboo is an important yet overlooked rich biomass resource that can stock carbon (Scurlock et al 2000, Ben-zhi et al 2005). Bamboo-centred agroforestry setups have demonstrated considerable promise in lessening GHG emissions and promoting global carbon absorption. Inclusion of bamboo in land use can bring sustainable climate change solutions to the farmers by sequestering carbon (Tu et al 2013) while giving attractive livelihood opportunities and food security to resource poor farmers (Basumatary et al 2015 and Panmei and Selvan 2024).Research indicates that bamboo species in our country can accumulate carbon at rates between 1-2.3 Mg per ha per year in AGB and 0.14-0.39 Mg per ha per year in soil, illustrating their importance in carbon agriculture and market (Subbanna and Viswanath 2021 and Debnath et al 2022). There is limited exploration of bamboo's capacity for carbon capture across the country. The current work was undertaken to know the quantum of emissions from crops in bamboo-based agroforestry systems and understand the carbon sequestration potential of the prevalent bamboo-based agroforestry systems.

MATERIALS AND METHODS

The primary field-work was performed in West Tripura district of Tripura, a North-Eastern state of India. It lies between 23°42′N - 24°5′N and 91°15′E – 91°35′E occupying an area of 10,486 km^2 at an average altitude of 12.80 msl. The state is charactered by warm and humid tropical climate with five different seasons viz., spring, summer, monsoon, autumn, and winter (https://tripura.gov.in/geographical-profile). Temperature varies from 20-36° C in summer and in winter, it ranges from 7-27° C. Rainy season is from June-September.

Data collection: Tripura have 21 species of bamboo among 130 species available in India bearing area of 3246 km^2 among 6294 km^2 of total RFA of the state. The bamboos are spread in wild, rural as well as peri-urban areas. In five peri-urban sites a total of fifty bamboo-based agroforestry farms were selected and an interaction was conducted (with their consent) on farmers/owners to collect information pertaining to greenhouse gas emission from their farm (Table 1).

Emission estimation: The GHG emissions of these farmlands were calculated by using “Cool Farm Calculator”. It is a web-based AI application designed for crops, or crop products providing unique results (Hillier et al 2011 and Jabbour et al 2021). This tool has been raised with the collaboration between University of Aberdeen, Unilever, and sustainable food lab in 2008 (Cool Farm Alliance 2020). This tool efficiently evaluates each system by examining the conditions that have the greatest impact on GHG emission. It is not only a calculator for GHG emission but also encourages management and helps to make action plans by creating "what if" situation (https://coolfarm.org/releasenotes).

Sequestration estimation: Sequestration was calculated for woody components i.e., for trees and bamboos. AGB of woody components was estimated.

$AGB = 0.0509 \times \rho D^2H$ (Chave et al 2005).

AGC was calculated as:

$AGC = AGB \times 0.47$ (Mcgroddy et al 2004).

This was estimated by using the default conversion factor of 47% of the overall biomass (Andreae and Merlet 2001 and Mcgroddy et al 2004). From AGB and AGC, the quantity of carbon-sequestered was calculated by using the following equation:

CO_2sequestered = AGC x 3.67

RESULTS AND DISCUSSION

Total emission from different crops in bamboo-based agroforestry: Emission (in kgCO_2e) from crops were estimated by input of primary data of land-use area, crops cultivated, management regime, energy and water use, volume of crop harvested, into the web-based AI tool "Cool Farm Calculator". The main sources of emission included application of nitrogen fertilizers, machinery use, land preparation practices etc. Emission across the 50 locations in the 5 sites are given in Table 2.

Total emission from each crop (27 species) in all the 5 sites (50 plots) are summed as 100,086.53kg CO_2e. The emissions varied significantly from crop-to-crop (Table 3). Among them, lowland rice had the highest emissions (total of 44828.98 kg CO_2e @ 4454.87kg CO_2e/ha) because of anaerobic conditions. This is due to release of methane and nitrous oxide in anaerobic situations in paddy cultivation (IPCC 2018). The lowland rice exhibited maximum emission levels in all sites, surpassing all other crops. This outcome also aligns with Mboyerwa et al (2022). Modification in management of fertilizer application at 100% NPK+Zn+FYM showed highest sequestration (Yaseen et al 2023) which indicate that incorporation of this technique may be able to curtail the emission from rice cultivation in the study sites. The other highGHG emitter varied across different locations and majorly included brinjal-*Solanum melongena*, green amaranth- *Amarathus cruentus*, bottle gourd-*Lagenaria siceraria*, pumpkin-*Cucurbita pepo*and chilli-*Capsicum*

Table 1. Site of bamboo-based agroforestry farms selected for greenhouse gas emission in West Tripura, India

Location	Name of the village	Latitude	Longitude
Suryamaninagar	Bellavpur	23.770242º	91.254464º
Suryamaninagar	Madhupur	23.764919º	91.260034º
Amtali	Kopali para	23.771156º	91.258954º
Amtali	Madhyapara	23.770181º	91.259074º
Barjala	Chandinamura	23.853835º	91.264413º

Table 2. Total emissions from all crops across the five study sites of bamboo-based agroforestry farms in West Tripura, India

Location code	Name of the location	Total emissions (kg Co_{2e})
S1	Bellavpur	14455.11
S2	Kopalipara	18533.17
S3	Madhyapara	20941.67
S4	Madhupur	32638.61
S5	Chandinamura	13517.97
Total		100,086.53

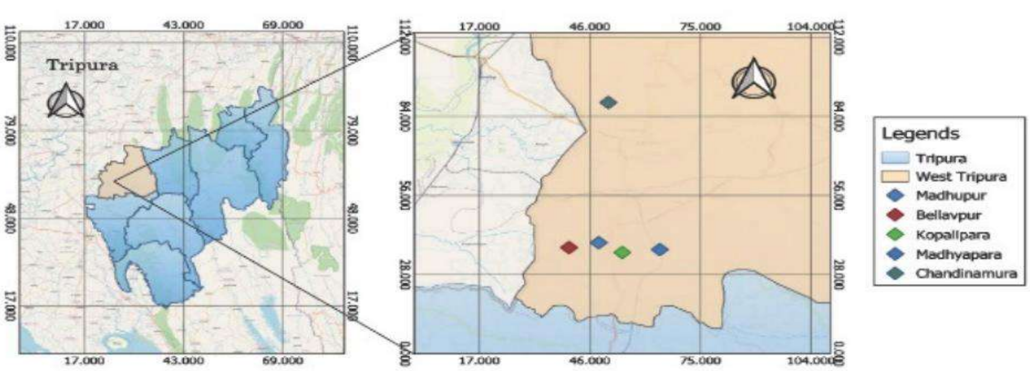

Fig. 1. Site of bamboo-based agroforestry farms selected for greenhouse gas emission in West Tripura, India

frutescens. Emission from chilli production can be positively controlled by effectively managing nutrient supply through fertigation (Nair et al 2024). The crop with second least emission was French bean-*Phaseolus vulgaris* (361.43 kg CO_2e/ha) showing low emission due to nitrogen fixing ability. Jeuffroy et al (2013) observed that incorporating nitrogen fixing crops in rotation can decrease nitrous oxide emission by 20-25%. Therefore, targeted initiatives must be taken to combine high-emission crops like lowland rice with low-emission crops, to substantially mitigate the environmental impact of agricultural activities (Li et al 2024). This study shows that emissions from various vegetables are also consistent. Fan et al (2021) concluded that proper application of organic fertilizer with appropriate irrigation strategies can reduce field emission. Further the rate of emissions varied from field to field depending on different factors like type of soil, type of crop, management practices.

Carbon sequestration by bamboo and woody trees: During the survey 34 woody species were encountered with 7 bamboo species, and 27 other tree species. A total of 362629.68 kg CO_2e was sequestered within the studied plots in all sites by the bamboos and the other woody tree species. The 7 species of bamboo found across all sites were viz. *Bambusa affinis, B. balcooa, B. polymorpha, B. tulda, B. vulgaris, Dendrocalamus hamiltonii* and *Melocanna baccifera.* Bamboo genetic resources are widely found in agroforestry land use across India (Selvan 2018). The total carbon sequestered by these bamboos stand at 91611.55 kg CO_2e which is 25.26% of the total carbon sequestered within the bamboo-based agroforestry land-use. *Bambusa tulda* has the

Table 3. Emission from crop and land-use management practices of bamboo-based agroforestry farms in West Tripura, India

Species/Crop	S1	S2	S3	S4	S5	Total per crop emission (kg CO_2e)	Emission from each crop (kg CO_2e/ha)
Abelmoschus esculentus	x	2	3	1	1	962.88	850.63
Amaranthus cruentus	2	4	2	2	2	7623.83	2728.96
Amaranthus dubius	x	x	x	x	1	184.25	842.48
Ananas comosus	x	x	x	1	x	2790	2682.69
Benincasa hispida	x	1	1	x	x	327.45	1445.35
Brassica nigra	x	1	1	x	x	797.51	1744.64
Brassica oleracea	x	1	x	x	x	94.56	152.52
Capsicum frutescens	1	4	4	2	x	4678.95	1127.30
Carica papaya	x	2	x	1	1	2856.44	1915.27
Citrus limetta	3	1	x	x	x	1290.67	1831.60
Citrus limon	1	1	x	x	x	662.89	1564.15
Coriandrum sativum	x	x	x	x	1	77.99	916.99
Cucumis sativus	2	x	x	1	x	818.77	2367.88
Cucurbita pepo	3	4	2	4	2	5748.83	1896.64
Cuminum cyminum	x	1	x	x	x	220.66	1050.76
Ipomoea batatas	x	1	x	x	x	155.46	536.07
Lagenaria siceraria	5	6	2	3	5	8751.80	2063.54
Moringa oleifera	x	1	x	x	x	306.3	831.09
Musa paradisiaca	x	5	x	2	x	2148.85	966.52
Oryza sativa	8	5	7	9	6	44828.98	4454.87
Phaseolus vulgaris	x	x	x	x	1	94.56	361.43
Raphanus sativus	x	x	x	x	2	433.23	2067.49
Solanum lycopersicum	2	2	2	x	x	578.76	1578.76
Solanum melongena	3	4	4	7	7	11676.55	1685.90
Vigna unguiculata	1	4	2	1	x	1076.97	582.37
Zea mays	1	x	x	x	x	535.6	2122.74
Zingiber officinale	x	1	x	x	x	363.79	1254.45
Total						100086.53	

The numerical values indicate the presence of the particular species in the n number of plots. X value indicate the absence of the species

Table 4. Carbon Sequestration by woody components including bamboo in the bamboo-based agroforestry land-use in West Tripura, India

Bamboo & other woody tree species	S1	S2	S3	S4	S5	Sequestration ($kgCO_2e$)	Sequestration (kg CO_2e/ha)
Albizia procera	x	x	x	1	x	2221.65	11594.92
Annona reticulata	1	x	x	x	x	248.32	3050.43
Areca catechu	5	5	6	4	5	33456.11	6065.98
Artocarpus heterophyllus	5	2	1	1	x	20269.33	13017.78
Azadirachta indica	x	x	x	x	2	318.54	1562.55
Bambusa affinis	3	2	5	1	3	23303.80	12107.58
Bambusa balcooa	1	1	x	x	x	2451.55	12537.16
Bambusa polymorpha	1	2	1	2	2	8934.83	11162.34
Bambusa tulda	1	x	2	1	x	23108.58	48030.89
Bambusa vulgaris	8	5	4	7	4	30575.29	9283.91
Borassus flabellifer	x	x	x	1	x	279.60	268.85
Carica papaya	x	x	x	1	1	127.91	252.53
Cocos nucifera	5	4	3	6	7	70390.65	13979.94
Conocarpus lancifolius	x	x	1	x	x	8.70	13.26
Corchorus olitorius	x	x	x	x	2	10.94	17.78
Dendrocalamus hamiltonii	x	x	1		x	6.45	13.16
Dipterocarpus turbinatus	1	x	x		x	5219.28	46025.35
Eucalyptus globulus	x	x	x	1	x	53.26	45.98
Gmelina arborea	3	x	x	x	1	4990.18	9186.01
Hevea brasiliensis	x	x	1	x	x	203.93	2257.94
Litchi chinensis	1	x	x	x	x	786.80	10388.81
Mangifera indica	3	6	9	8	*9*	78569.79	11828.81
Melocana baccifera	x	3	x	x	1	2813.62	3561.67
Mesua ferrea	x	1	x	x	*x*	2025.21	7023.18
Moringa oleifera	x	1	x	x	x	908.94	2466.25
Musa paradisica	x	x	2	5	1	2134.68	1498.21
Polyalthia longifolia	x	2	3	x	1	12009.35	12992.22
Saraca asoca	x	x	1	x	x	116.11	236.94
Shorea robusta	x	x	x	x	1	19.45	74.36
Swietenia macrophylla	x	1		x	x	2640.65	15269.61
Syzygium cumini	1	x	9	6	x	20917.67	4651.92
Tectona grandis	2	1	1	1	1	10901.94	11101.5
Terminalia arjuna	1	x	x	x	x	647.08	4992.93
Vachellia nilotica	x	x	x	x	1	526.52	2012.44
Ziziphus mauritiana	1	x	x	x	1	1085.34	4026
Total						362629.68	
Sequestration from Bamboos						91611.55	

The numerical values indicate the presence of the particular species in the n number of plots. X value indicate the absence of the species

highest carbon sequestration potential (48030.89 CO_2e/ha). High carbon sequestration in this study was in *Artocarpus heterophyllus* (13017.78kg CO_2e/ha) which was also encountered by Jithila and Prasadan (2018). *Areca catechu* and *Cocos nucifera* are excellent in carbon capture despite its slender form, thus can be easily incorporated as boundaries. Sudha et al (2021) observed that coconut in agroforestry systems with other tree components are very effective in carbon sequestration. *Polyalthia longifolia* (12992.22 kg CO_2e) is a good tree for carbon sequestration. Net carbon capture by *Gmelina arborea* based agroforestry has been much more higher than sole cropping system (Kumar et al 2024) which is consistent with the result for *Gmelina arborea* (9186.01kg CO_2e/ha). Ganeshamurthy et al (2019) showed that carbon-sequestration rate by *Magnifera indica* is quite good. *Mangifera indica* had sequestered total of 78569.79 Kg CO_2e (11828.81 kg CO_2e/ha) which is amongst the highest in all the species. This is also due to its presence in all the sites. Leguminous trees-*Moringa oleifera* (2466.25kg CO_2e/ha) and *Albizia procera* (11594.92 kg CO_2e/ha) showed high sequestration rate. Guleria et al (2014) and Rosenstock (2014) also indicated nitrogen-fixing trees positively influences growth in biomass of the plant that ultimately increase the carbon fixation.

Net emission: The net emission is the difference between the sequestration and emission from the land-use 262543.15 kg CO_2e. Positive net emission was observed from the tree component in agroforestry systems due to sequestration upto the tune of 90% (Sudha et al 2021). The net emission was significantly higher in poplar-based wheat agroforestry system as compared to the open farming of wheat (Chauhan et al 2010, Chauhan et al 2010, Kumar et al 2020). Integrating trees and bamboo with agricultural practices can achieve considerable net carbon sequestration, effectively neutralizing the emissions associated with crop farming (Sharma et al 2016, Selvan et al 2023).

CONCLUSIONS

The emission from all crops in cultivation on all sites was 100086.53kg CO_{2e} while the sequestration by bamboos and other woody components in the land-use was 362629.68 kg CO2e. Bamboo accounts for 25.26% of the sequestration with *Bambusa tulda* being the best performer. This study emphasizes the potential of integrated farming system in improving carbon-sequestration and mitigating the overall carbon footprint in agricultural practices. The study also observed that results varied greatly depending upon the management practices/ land-use regimen and the post production transport to market. The advantageous net carbon balance highlights the dual merits of incorporating tree and bamboo cultivation in agricultural practices increasing carbon capture and offering supplementary economic, greater livelihood options and ecological improvements. Therefore, this study encourages the wider application of integrated agricultural systems as a viable solution to attain food security, livelihood generation and carbon neutrality.

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Effect of Silkworm Larval Population Density on Quality of Cocoon Production

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***Abstract*:** Larval population has a great impact on biology and physiology of insects including silkworm *Bombyx mori* L. The present study was conducted on hybrid CSR_2× CSR_4, comprising of seven treatments. Thepopulation density of silkworm larvae varied from 250 worms per plastic tray size (6ft.) to 550 wormsper tray to evaluate and recommend the optimum silkworm population number required to be reared under specific unit area commercially. Fourteen commercial characters were studied and evaluated by cumulative Mano's Evaluation Index (E.I.) method. The late age larval duration of the silkworm is directly proportional to the larval density, while as larval weight depicts relatively inverse relation. The highest E.I value of 56.30 was obtained for 250 population size. For population size of 300, 350, 400 silkworm the E.I values recorded were, 54.16, 52.42, 51.21 , respectively. The study also revealed that with the increase in larval population per square feet, the economic rearing parameters get reduced in metric traits. More density affects quantitative traits than qualitative traits. The larval population density 300 to 400 larvae/tray is economically and commercially optimum and advocated for field rearing.

Keywords: Silkworm, *Bombyx mori*, Population density, Cocoon production

The mulberry silkworm, *Bombyx mori* L. (Lepidoptera: Bombycidae) is a commercially important insect that spins 95-99 per cent of the valuable silk fibres for both textile and non-textile industry. As sericulture is increasingly becoming an income-generating activity in rural economies, improving the rearing environment can significantly boost both productivity and profitability. Rearing performance affects sharply in their ecological, biochemical, physiological and quantitative characters, which influence growth and development, and quantity and quality of silk produced in different geographical locations, and thus, varies under different ecological conditions to make silkworm rearing cost effective and more productive (Tilahun et al 2017).

The success of sericulture industry and cocoon productivity depends upon several factors of which the impact of the population density during the ultimate larval instar stadium is one of the crucial issues for successful cocoon crop production (Reddy et al 2015). Silkworm density play an important role in physiological programming of growth of different instars of larvae in relation to bed cleaning (Tilahun et al 2015) and optimum spacing to ensure good feeding appetite andto get quality cocoon production. Since the silkworm grow very fast particularly in the young age, the rearing seat is also to be proportionately increased. As the larvae progress through different developmental stages, growing exponentially from the initial instar to the point where they are ready to spin, the requirement for rearing space expands substantially by 80-100 times.

The overcrowding conditions developed during rearing create a suboptimal micro-environment which leads to insufficient space for silkworms to feed and move freely. The high population density increases humidity, produces excessive heat, and facilitates the fermentation of faecal matter. Krishna et al (2021) found that as the density of silkworms per rearing tray increases, larval weight and growth rate decrease significantly. The development of such type of condition can impair the metabolism of larvae, induced stress and hinder their growth, resulting in weak, underdeveloped larvae prone to disease outbreaks. As a result, this adversely affects key commercial traits, including cocoon weight, shell ratio, and the length and strength of the silk fibre.

Moreover, high-population larval density can delay the development cycle, reduce feed conversion efficiency and cause extended larval periods which elevate mortality rates, leading to a sharp decline in overall productivity. Consequently, this imbalance in nutritional uptake and physiological stress in an over- crowded environment weakens cocoon formation, resulting in the formation of defective cocoons with poor-quality silk filaments. Singh and Yadav (2023) concluded that silkworms spin cocoons with thinner shells, leading to a lower shell ratio when reared at higher densities. Thus, it is very important to avoid overcrowding in order to maintain a healthy and productive rearing environment. However, providing more space than optimal need can result in wastage of mulberry leaves, inefficient resource management and increased labour costs for feeding. Therefore, to achieve a sustainable sericulture rearing, it is essential that the density of population in the rearing bed should be regulated and ideal rearing bed conditions are ensured.

Considering the need to improve cocoon yield and silk quality and the economic significance of silkworm rearing as a source of income, this study was envisaged to assess the impact of larval population density on the production of high-quality cocoons.

MATERIAL AND METHODS

The present study was carried out during spring rearing season at Sher-e-Kashmir University of Agricultural Sciences and Technology, Jammu. Seed of $CSR_2 \times CSR_4$ was procured from RSRS, Dehradun and released from cold storage, incubated and reared as per the standard rearing techniques at silkworm research laboratory of Division of Sericulture at SKUAST-Jammu.(Krishanaswamy 1978). The number of larvae per rearing tray(2×3=6ft) were 250, 300, 350, 400, 450, 500, and 550 in such a way that each tray represents a single independent replicate in a completely randomized design. Each treatment was replicated 4 times. The rearing tray with 250 larvae served as control (standard). Following observations were made for different parameters:

Weight of 50 mature larvae (g): Fifty mature larvae were picked randomly from each replicate from 4 to 6 day of fifth instar and weighed using digital balance. The maximum larval weight was recorded in each replicate.

Larval survival percentage: The larval survival percentage represents the number of worms surviving during rearing up to pre spinning stageand was calculated by using the following formula:-

$$\frac{\text{Number of larvae surviving at pre-spinning stage}}{\text{Total number of larvae retained after III moult}} \times 100$$

Cocoon yield/10000 larvae

By weight (kg): This parameter was recorded as an average weight of cocoons harvested in kg converted for 10,000 larvae and was worked out by using the by following formulae:-

$$\text{By weight} = \frac{\text{Cocoon yield in kg}}{\text{Total number of larvae retained after III moult}} \times 10{,}000$$

By number: It was recorded as an average number of cocoons harvested and converted for 10,000 larvae and was worked out by using the by following formulae:-

$$\text{By number} = \frac{\text{Cocoon yield by number}}{\text{Total number of larvae retained after III moult}} \times 10{,}000$$

Single cocoon and shell weight (g): Twenty five male and twenty five female cocoons were randomly selected and weighed on digital balance to determine the average cocoon weight by using the following formula:

$$\frac{\text{Weight of 25 male (g)+25 female cocoon (g)}}{50}$$

Shell ratio percentage: Shell ratio was calculated is as:-

$$\frac{\text{Average weight (g) of 25cocoon shells of each sex}}{\text{Average weight of same cocoons of each sex}} \times 100$$

Total filament length (m): Filament length indicates the total reelable length of silk filament obtained from a single cocoon in meters. It is the average length of the silk reeled from a single cocoon.

$$\text{TFL} = \frac{\text{Length of raw silk reeled (m)} \times \text{No. of cocoons maintained per end}}{\text{No of reeling ends*}}$$

*Number of reeled cocoons = Number of cocoons taken for testing – Number of new unreelable cocoons/Number of converted carry over cocoons

Non-breakable filament length (m): It is a length at which cocoon filament breaks and is replaced by another cocoon. It was recorded as per the following formula:-

$$\text{NBFL} = \frac{\text{Length of silk filament reeled} \times \text{No. of cocoons maintained per end}}{\text{No of reeling ends*}}$$

*Indicates number of castings + Number of carry over cocoons – Number of converted carry over cocoon.

Filament size (d): It was determined by using filament reeled from ten cocoons from each replicate and it was calculated by using the following formula:-

$$\frac{\text{Weight (g) of raw silk reeled}}{\text{Length (m) of silk reeled} \times \text{No. of cocoons maintained per end}} \times 9000\ \text{(m)}$$

The observations were recorded on different parameters at larval, cocoon and the post cocoon parameters were evaluated by Evaluation Index method.

Evaluation index: Evaluation Index (E.I.) is the performance index which a single value measure of the multiple trait performance of a population Mano et al (1993).

$$\text{E.I.} = \frac{A-B}{C} \times 10 + 50$$

Where,

A = Value obtained for a particular trait of the hybrid combinations.

B = Mean value of a particular trait of all the hybrid combinations.

C = Standard deviation of a particular trait.

10 = Standard unit

50 = Fixed value gives

E.I. values for quantitative and qualitative characters surpassing the E.I. bench mark value >50 will be considered.

RESULTS AND DISCUSSION

Larval growth parameters: The observation made on the weight of fifty mature larvae and larval survival percentage depicted significant variation. The E.I. value greater than 50 was recorded in the population density of 250 larvae/6ft

(61.20) for the weight of 50 mature larvae, followed by 300 larvae (58.35) and 350 larvae (56.65) respectively, which clearly indicated that larval weight was favourably impacted by lower population densities (Table 1). This may be due to less number of worms in the rearing tray leads to robust growth and development and the competition for food is also less and the result collaborates with the findings of (Reddy et al 2015). In terms of larval survival percentage, a crucial parameter for maximizing cocoon yield, the E.I. value was higher in the 250 larvae/6ftpopulation (60.16). Densities above 450 larvae showed a significant drop in survival rates, likely due to increased disease incidence (Dutta et al 2013). High densities have been linked to a higher incidence of silkworm diseases like grasserie (Kumar et al 2014). Average E.I. for weight of 50 mature larvae and larval survival per cent was in 250 (60.68) followed by 300 and 350 population surpassing the benchmark of >50 (Table 1).

Cocoon parameters: The cocoon yield/10,000 larvae by weight and by number was significantly higher in the lower density populations (250-400 larvae) (Table 2) and this may be due to the fact that larval survival percentage was higher in less density population when compared to higher density population of larvae. Overcrowding of worms (450-550 larvae) resulted in more double and flimsy cocoons, which is considered to be negative and undesirable character for any breed/hybrid (Kamaraj et al 2016). Good cocoon and pupation percentage can be the attribute of rearing space, hygiene and appropriate time for picking mature larvae for seriposition. Maximum E.I. value for larval density was of 250 (61.18) followed by larval density of 300, 350 and 400. The spacing played a vital role in good cocoon percentage as well as the robustness of the breed. Current findings also provide evidence that spacing of worms is an important character and population density is directly correlated with good cocooning (Vemananda et al 2004). For pupation rate, maximum E.I. of 60.87 was scored by 250 larvae/tray followed by 300 (57.20), 350 (56.23) and 400 (53.16) while the population density of 550 larvae/6 ft² exhibited the lowest non-significant E.I. value (31.44), indicating reduced pupation success in denser populations.

Table 1. Evaluation Index values of silkworm hybrid on weight of mature larvae and larval survival percentage

Larval population/ tray	Weight of 50 mature larvae (g)	Larval survival (%)	Total	Average
250	61.20	60.16	121.36	60.68
300	58.35	58.99	117.34	58.67
350	56.65	56.39	113.04	56.52
400	49.81	51.46	101.27	50.63
450	47.72	50.00	97.72	48.86
500	39.36	38.01	77.37	38.68
550	36.89	34.92	71.81	35.90

The cocoon weight, shell weight and shell ratio are important commercial parameters of cocoon stage for quality reeling performance. The cocoon weight has a negative correlation with the shell ratio but positive correlation with shell weight. While single cocoon weight and single shell weight showed no significant differences across different densities, shell ratio important for silk reeling, revealed that the E.I. value > 50 was observed in population size of 250 (60.34), 300 (54.18) and 350 (50.93) respectively. Among selected seven populations size for all important commercial cocoon parameters, the average E.I. ranged between 42.04 (550) and 57.06 (250). Four out of seven population size 250 larvae (57.06), 300 (54.35), 350 (51.69) and 400 larvae per tray (50.09) crossed E.I. benchmark of >50 indicating that lower population densities generally yielded superior cocoon quality and productivity. The results are in accordance with the findings of Subramanian et al (2013) (Table 2).

Post cocoon characters have greater significance not only from reelers point of view but also from industrial point of view. Three post-cocoon parameters viz., total filament

Table 2. Evaluation index of bivoltine silkworm hybrid on different spacing for cocoon traits

Larval population/tray	Cocoon yield By Wt. (g)	Cocoon yield By No.	Good cocoon per cent	Pupation per cent	Double cocoon per cent	Flimsy cocoon Per cent	Single cocoon weight (g)	Single shell weight (g)	Shell ratio	Total	Avg. E.I.
250	58.79	58.82	61.18	60.87	39.58	42.37	60	70 .00	62 .00	513.61	57.06
300	61.56	54.84	57.36	57.20	41.65	42.61	55	60 .00	59 .00	489.22	54.35
350	51.48	53.52	56.23	56.25	42.06	42.71	53	60 .00	50 .00	465.25	51.69
400	52.76	55.43	53.16	53.28	49.5	47.76	49	50 .00	49 .00	459.89	51.09
450	47.80	53.31	49.12	49.12	57.93	50.99	45	50 .00	45 .00	448.27	49.80
500	45.88	40.01	41.76	41.76	54.87	54.15	45	50 .00	42 .00	415.43	46.15
550	30.78	34.05	31.44	31.44	64.38	69.30	36	40 .00	41 .00	378.39	42.04

Table 3. Evaluation index of bivoltine silkworm hybrid on different spacing for post cocoon traits

Larval population/tray	Total filament length (m)	Non-breakable filament length (m)	Filament size (d)	Total	Average
250	58.10	56.36	38.89	153.35	51.11
300	56.03	53.95	41.85	151.83	50.61
350	55.27	53.36	47.03	155.66	51.88
400	55.17	52.12	48.51	155.80	51.93
450	47.11	49.50	51.48	148.09	49.36
500	41.95	45.88	58.51	146.34	48.78
550	36.33	38.79	64.81	139.93	46.64

Table 4. Cumulative evaluation index of bivoltine silkworm hybrid on different spacing for commercial traits

Population size		250	300	350	400	450	500	550
Wt. of 50 mature larvae		61.20	58.35	56.65	49.81	47.72	39.36	36.89
Larval survival		60.16	58.99	56.39	51.46	50.00	38.01	34.92
Cocoon yield per 10,000 larvae	Wt.	58.79	61.56	51.48	52.76	47.80	45.88	30.78
	Nos.	58.82	54.84	53.52	55.43	53.31	40.01	34.05
Good cocoon		61.18	57.36	56.23	53.16	49.12	41.76	31.44
Double cocoon		39.58	41.65	42.06	49.5	57.93	54.87	64.38
Flimsy cocoon		42.37	42.61	42.71	47.76	50.99	54.15	69.3
Pupation		60.87	57.20	56.25	53.28	49.12	41.76	31.44
Single cocoon weight		60	55	53	49	45	45	36
Single shell weight		70	60	60	50	50	50	40
Shell ratio		62	59	50	49	45	42	41
Total filament length		58.10	56.03	55.27	55.17	47.11	41.95	36.33
Non-breakable filament length		56.36	53.95	53.36	52.12	49.50	45.88	38.79
Filament size		38.89	41.85	47.03	48.51	51.48	58.51	64.81
Total		788.32	758.34	733.95	716.96	694.08	639.14	590.13
Average E.I.		56.30	54.16	52.42	51.21	49.57	45.65	42.15
Rank		I	II	III	IV	-	-	-

length, non-breakable filament length and filament size contribute largely for silk, the end product. Population size 250 larvae scored maximum non- breakable filament length having E.I. value of 56.36 followed by 300, 350 and 400, while as the population 500 scored lowest E.I. value of 38.79 (Table 3). An inverse trend compared to other parameters was observed in filament size, with higher population densities yielding thicker filaments. The 550 larvaepopulation had the significant E.I. value (64.18), followed by 500 larvae and 450 larvae, and with non-significant differences observed in lower population densities, such as 250 larvae/6 ft.Among seven different population size the average E.I. values ranged between 46.64 (550) to 51.11 (250 larvae/tray). The result collaborates with the findings Kumari et al (2000).The fourteen commercial quantitative and qualitative traits revealed broad variability between different population densities. This may be attributed to the adaptability of silkworm larvae to different population size in the rearing space/environment. The cumulative results based on the E.I. values from the present investigation clearly indicates that rearing of silkworm with population size of 250 larvae with E.I. 56.30 expressed better results followed by larval population density of 300 , 350 and 400) (Table 4).

CONCLUSION

The population density of 300-400 per 6 ft allows the larvae to thrive due to reduced competition for food and space resulting in superior outcomes across commercial parameters such as larval survival, cocoon weight, shell weight, and post-cocoon traits and strike equilibrium between maintaining efficiency for commercial sericulture and ensuring optimal cocoon characteristics. This study can be highly optimum for field rearing and will be helpful for sericulturists to achieve better economic returns through improved cocoon yields and silk quality while minimizing the risk factors associated with higher densities.

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Role of Traditional Knowledge in Modern Era for Sustainable Utilization of Forest Produce in Central India

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***Abstract*:** Food security and sustainability are major global concerns, particularly in Central India where tribal women are vulnerable to hunger and malnutrition. This study explores the crucial role that traditional knowledge plays in promoting sustainable utilization of non-timber forest products in Central India. The study is conducted by interviewing 40 tribal women of age group 20-60 years from three villages in Katghora Forest Division. The Study emphasizes the significance of forest products in the nutritional well-being of tribal families. Forest produce, such as wild fruits, tubers, and medicinal plants, are not only rich in nutrients but also hold the key to sustainable food security for future generations. This paper highlights the symbiotic relationship between traditional practices and modern healthcare, underscoring how these ancient practices align with Sustainable Development Goal 2 (SDG 2) to end hunger, achieve food security, and promote sustainable agriculture. It is observed that more than 42% of tribal women are dependent directly on traditional knowledge from the nearby forest, while other tribal women rely indirectly. They also practice some traditional and some modern methods for better consumption of the foods. These practices guarantee that the resources are harvested in a way that keeps them available for future generations and supports sustainable livelihoods without depleting the forests resources.

***Keywords*:** Traditional knowledge, Sustainability, Food, NTFPs, Tribal women

Traditional knowledge systems have been acknowledged as valuable in many parts of the world for their role in resource conservation and sustainable agriculture (Turner and Clifton, 2009). In India, specifically in tribal-dominated regions like central India, NTFPs play a critical role in the daily lives of the indigenous population (Xess et al 2024). These forest products not only provide nutrition but also form the backbone of rural economies.Central India, known for its rich biodiversity, hosts a large population of forest-dependent communities that rely heavily on traditional knowledge and forest resources for sustenance (Tiwari 2015).

Central India is home to vast stretches of forest that serve as the primary source of livelihood for its tribal population. These tribal communities possess a wealth of traditional knowledge related to the use of non-timber forest products, which plays an essential role in ensuring food security and health in an era where hunger and malnutrition are still prevalent (Sabar et al 2024). Studies have demonstrated the nutritional superiority of wild forest foods in many indigenous communities (Bharucha et al 2010). These foods, such as tubers, wild fruits, and leafy vegetables, are rich in vitamins and minerals, often surpassing domesticated crops in nutritional value (Mohd Salim et al 2023). Moreover, traditional harvesting techniques, which emphasize sustainable practices, ensure the continued availability of these resources for future generations.

The importance of traditional knowledge in addressing SDG 2-ending hunger, achieving food security, and promoting sustainable agriculture-cannot be overstated. The information needed for the sustainable use of plants is frequently qualitative, confined to a certain geographic area, and dependent on observation. These traditional knowledge were gathered by tribal people and passed down through culture practices from their predecessors (Patra 2022, Xess et al 2023). This study investigates the intersection of traditional knowledge and modern food security, focusing on the sustainable use of forest products in Chhattisgarh.

MATERIAL AND METHODS

To study the role of traditional knowledge in modern food security, a semi-structured interview-based on traditional knowledge and practices was conducted in three villages-Puta (latitude: 22.822054 longitude: 82.706585), Pachra (latitude: 22.697017 longitude: 82.447919), and Buka (latitude: 22.721192 longitude: 82.532473)-located in the Katghora Forest Division, Korba, Chhattisgarh. A total of 40 tribal women of age group 20-60 years were interviewed, focusing on their traditional practices, utilization of forest products, and their contributions to household nutrition and healthcare. Data were gathered through direct interaction with the participants, supplemented by field observations.

RESULTS AND DISCUSSION

Importance of NTFPs in food security: NTFPs are an integral part of tribal diets in Central India. The commonly harvested forest products include wild fruits, leafy greens, tubers, and medicinal plants. These foods, often rich in micronutrients, are vital in combating malnutrition, especially among children and elderly individuals in the tribal communities. The survey has identified the gender relationship and the critical role that tribal women play in the collection, processing, management, and conservation of forests and forest products, over 42% tribals women of the surrounding forest area depends directly on NTFPs in the sites mentioned, while other tribal women depend on NTFPs indirectly, primarily bringing forest resources that meet their specific needs, such as edible leaves, tubers, and therapeutic plants like fuel wood, seeds, mushrooms, greenery, and other forest produce items.

The 62% tribal women of Puta village are more often visiting the forest for the collection of forest produce. The amount of NTFP collected and used is primarily driven by

Table 1. Average forest visit and forest produce utilization

Village	Average no. of forest visit per month (%)	Average no. of NTFP and forest produce utilization per day (%)
Puta	62	72
Pachra	51	63
Buka	37	56

Table 2. Important NTFPs collection (Xess et al 2023)

Common name	Scientific name	Family	Flowering season	Fruiting season	Harvesting month	Collection rate (per kg)
Tendu	*Diospyros melanoxylon*	Ebenaceae	April- May	May- June	June	
Sal	*Shorea robusta*	Dipterocarpaceae	April- May	May	May- June	20.00
Kusum	*Schleichera oleosa*	Sapindaceae	January- February	March- April	July- August	23
Bahera	*Terminalia bellirica*	Combretaceae	April-May	May	November-February	17.00
Imli	*Tamarindus indica*	Fabaceae	April-June	February-March	March-April	36.00
Chironjii	*Buchanania lanzan*	Anacardiaceae	January-February	March-April	April-May	126.00
Mahua	*Madhuca indica*	Sapotaceae	March-April	April	May-June-July	29.00
Kalmegh	*Andrographis paniculata*	Acanthaceae	March- April	March- April	September	35.00
Charota	*Cassia obtusifolia*	Fabaceae	March- September	May- September	November	16.00
Harra	*Terminalia chebula*	Combretaceae	April- May	May- June	November- February	15.00
Van tulsi	*Ocimum gratissimum*	Lamiaceae	--------	--------	-----------	16.00
Honey	---------------	-----------	-----------	-----------	October/ November and February- June	225.00
Shatavari (roots)	*Asparagus racemosus*	Asparagaceae	July	September	November- December	107.00
Shikakai	*Acacia concinna*	Mimosaceae	October- November	December- January	April- May	50.00
Nagarmotha	*Cyperus rotundus*	Cyperaceae	March- July	July-september	October- November	30.00
Kusumi (Lac)	*Kerria lacca*	Kerridae	-----------	------------	------------	300.00
Rangini (Lac)	*Acacia catechu*	Fabaceae	March- September	March- September	March- September	220.00
Giloy	*Tinospora cordifolia*	Menispermaceae	May- June	September- October	November	40.00
Bhelwa	*Semecarpus anacardium*	Anacardiaceae	December- January	February- May	May- June	09.00
Dhawai (Flower)	*Woodfordia fruticosa*	Lythraceae	February- April	April- May	May	37.00
Kullu gond	*Sterculia urens*	Sterculiaceae	December- March	April- May	April- June	125.00
baelguda	*Aegle marmelos*	Rutaceae	March-April	April- June	April-May	30.00
Karanj	*Millettia pinnata*	Fabaceae	April-June	May- June	November- December	22.00
Neem	*Azadirachta indica*	Meliaceae	April	June- July	July- August	27.00
Jamun	*Syzygium cumini*	Myrtaceae	March- May	May- June	July- August	42.00

women of Puta village i.e. 72%, who also benefit from it in terms of their wellbeingand household uses. They sell some of the forest produces like tendu, mahua, ber, char, mango etc. for their income generation which also enhances their income profile. In Tendu and Mahua forest produce are highly utilized by the tribals and mushroom, bamboo crafts and tamarind are less utilized by the tribal women of Katghora forest division. The utilization of NTFPs by tribal women indicate more dependent on forest resources for their livelihood and income generations

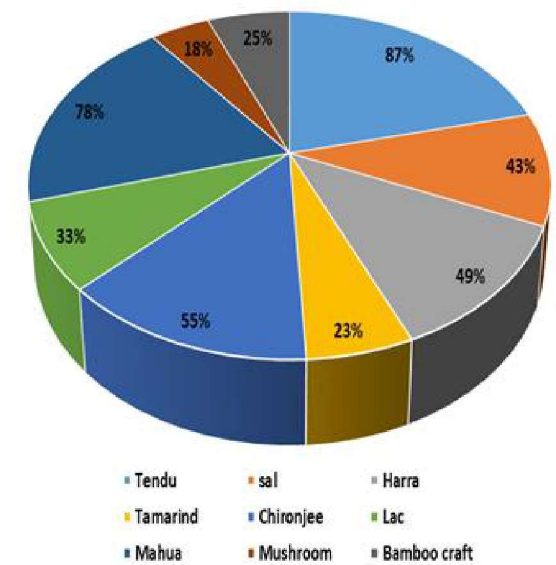

Fig. 1. Percentage of NTFP utilization

Role of tribal women in household food security and health care: The traditional food is found more beneficial in Puta village for sustaining and defending health of tribal women as well as providing indigenous nutrients in the best possible ways. Foods including 59,22and 18% vegetables, tubers and wild fruits, which are nutritious andalos abundantly found in these areas. Tribal women also gather roots, tubers, leaves, flowers, and fruits from the forest to supplement their diets which provides the 63% of traditional, distinctive natural flavours and health advantages to tribal

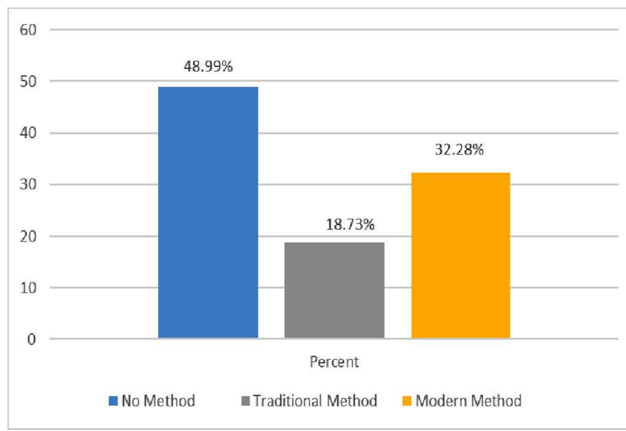

Fig. 2. Percentage of utilization of traditional and modern method

Table 2. Harvestable plant parts through non-destructive harvesting techniques

Common name	Scientific name	Family	Harvestable part
Mahua	*Madhuca indica*	Sapotaceae	Riped fallen flower
Tendu	*Diospyros melanoxylon*	Ebenaceae	Tender leave
Kachnar	*Bauhinia variegata*	Caesalpinioideae	Tender leave
Moringa	*Moringa oleifera*	Moringaceae	Tender leave, fruit
Bohar	*Cordia dichotoma*	Boraginaceae	Tender fruit
Mushroom	*Agaricus silvicola*	Agaricaceae	Tender fruit
Kusum	*Schleichera oleosa*	Sapindaceae	Ripped fruit
Birhool			Flower
Char	*Buchanania lanzan Spreng.*	Anacardiaceae	Ripped fruit
Ber	*Ziziphus mauritiana*	Rhamnaceae	Ripped fruit
Shatavari	*Asparagus racemosus*	Asparagaceae	Roots
Adusa	*Adhatoda vasica*	Acanthaceae	Young shoots and tender leaves
Poin			Tender leaves
Amaltash	*Cassia fistula*	Fabaceae	Flower
Jhirhul	*Indigofera cassioides*	Fabaceae	Leaves
chakora	*Cassia obtusifolia*	Fabaceae	Tender leaves

women. They also practice some traditional and some modern methods for better consumption of the foods. In terms of some traditional methods 18.73% of the tribal women cook the raw food. But in terms of some modern methods, 32.28% of tribal women are always very keen to learn various new cooking skills and various new cooking procedures for collected raw food items.

Sustainable harvesting practices: The tribal women emphasize the techniques that involve minimal damage to the forest ecosystem. Non-destructive harvesting method is used by tribals. Like fruits are harvested selectively, allowing the plants to regenerate. Tubers are gathered in a way that leaves the root system intact, ensuring that the plant can continue to grow. As compared to all the three villages 40% tribal women of puta are harvesting sustainably through non-destructive harvesting techniques where as 28% and 21% tribal women of Pachra and Buka are harvesting sustainably through non-destructive harvesting techniques respectively. The maximum harvested parts of the plants approx. 66% are fruits and leaves rest other are around 24-34% roots, tubers and flowers.

CONCLUSION

The sustainable utilization of forest products is rooted in the traditional knowledge of Central India which offers a viable pathway to achieve food security and improve nutrition. By leveraging traditional non-destructive harvesting practices, tribal women are able to protect their natural resources while ensuring a steady supply of nutritious forest foods like wild fruits, leafy green edible parts, tubers, and medicinal plants. Moreover,in today's generation tribal women are practicing traditional knowledge more on day-to-day life as compared to urban women. More often the tribal women are frequently visiting to the forest for the collection and utilization of the forest produces and they are very keen to learn the traditional methods in a modern way. The findings of the study underscore the need for greater recognition of the role that traditional knowledge can play in the modern era by integrating traditional knowledge into modern food security and healthcare strategies like conservation of forest resources in sustainable manner so that future scarcity of food can be reduce and by adapting traditional knowledge in modern culture will help to maintain the hygienic, less disease and healthy lifestyle, especially in remote regions where access to modern medical facilities is limited. The tribal women, as custodians of this knowledge, play a crucial role in ensuring the sustainability of these resources. So proper documentation of the traditional knowledge can actually enhance the better living standards and provide the opportunities to the tribal women which can help to prevent the loss of traditional knowledge and can be a valuable source for future upcoming generations

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Long-term Spatio-temporal Variation of Meteorological Drought in Northwest India

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***Abstract*:** This study focuses on the spatial and temporal patterns of meteorological drought by analyzing the monthly distribution of rainfall and temperature across Punjab and Haryana in Northwest India. The rainfall and temperature analysis was done from 1966 to 2017. The trend change was assessed using the Mann-Kendall test. Standardized potential evapotranspiration index (SPEI) was used to estimate the wetness and dryness for different months and seasons, with special reference to rice (SPEI-5 June-October) and wheat (SPEI-5 November-March) growing seasons during the study period. The analysis shows that Punjab has a significant increasing trend of meteorological drought. It was reported in the Gurdaspur (SPEI-5 October) and the South-western districts of Ferozepur and Bathinda (SPEI-5 March). In Haryana, significant increasing trends of meteorological drought were observed in Ambala, Gurgaon, Karnal, and Rohtak during (SPEI-5 October) and, Hisar and Rohtak in (SPEI-5 March). A comprehensive understanding of precipitation and temperature variability, trends, and change points is of unprecedented interest to a researcher because it is required for developing better contingency plans to mitigate the effects of climate change and increase future resilience.

Keywords: SPEI, Mann-Kendall, Temperature, Rainfall, Spatial, Temporal

Climate change increases the magnitude and frequency of rainfall extremes, posing a greater risk of drought and flooding (Chen et al 2014). It is a continuous process that has occurred in the past, is happening now, and will continue in the future. As observed in other parts of the country, the climate in northwestern India has changed dramatically. Spatial and temporal changes in the weather variables affect the climate and the hydrological cycle, with agronomic and environmental consequences (Kang and Banga 2013, Jalota et al 2013). Punjab and Haryana, located in Northwest India, experience a semi-arid and tropical climate. Punjab is divided into five agro-climatic zones; the sub-mountain undulating region, undulating plain region, central plain region, western plain region, and the western region whereas Haryana has two agro-climatic zones; the southwestern zone and the north-eastern zone. The complex topography of this region leads to significant spatial and temporal variations in rainfall. These states experience monsoon-dominated rainfall, with Punjab receiving 200-1000 mm annually and Haryana receiving 300-1000 mm, depending on location. Both states also receive some rainfall from western disturbances throughout the year. In Punjab, the rainy season lasts from June to September, with rainfall ranging from 200 to 1000 mm. In Haryana, annual rainfall ranges from 300 mm in the southwest to 1000 mm in the Shivalik hills region. Around 75% of the rainfall occurs during the monsoon, with the remaining 25% spread throughout the year.

Droughts are severe and frequent in India's northwestern region, which is arid and semiarid. Meteorological drought occurs once every three years in all districts in Punjab where it occurs once every four years, and droughts have taken place once every three years in nearly half of Haryana's districts, with the remaining experiencing droughts once every four years. As a result, the high and low rainfall anomalies can cause economic and humanitarian crises (World Bank 2006). Understanding the spatial and temporal variability of rainfall and temperature, therefore, becomes critical for predicting and mitigating the impact of droughts. This study seeks to assess the long-term spatial and temporal changes in meteorological droughts across Northwest India, with a focus on the states of Punjab and Haryana. By analyzing historical trends in rainfall and temperature using gridded data and robust statistical methods, the study seeks to provide insights into regional climate dynamics and support the development of effective strategies for drought mitigation and climate resilience.

MATERIAL AND METHODS

Study area: The study is conducted in the Punjab and Haryana. The research is based on gridded precipitation and temperature data sourced from the India Meteorological Department, Pune (https://www.imdpune.gov.in/Clim_Pred_LRF_New/Grided_Data_Download.html) at the district level for 52 years (1966-2017). Gridded rainfall and temperature data sets have been used in numerous hydrological and climatological studies (Tozer et al 2012). Daily grid data of rainfall (0.25° x 0.25°) and maximum and minimum temperature (1°x1°) were extracted using the QGIS (3.22) python console. Since the gridded temperature data is 1°x1°, some districts do not have gridded data points. So, the study employed a commonly used interpolation technique, Inverse Distance Weighting (IDW) (Burrought 1986, Schut 1976), which is based on the assumption that the variables at a projected point are similar to the values at adjacent observation points (ESRI 1992). Using ArcGIS 10.4, temperature (maximum and minimum) data were interpolated to 0.25°x 0.25° grids. The daily average of the gridded temperature and rainfall data was calculated for each district, which was then aggregated monthly.

Analytical Framework

Standardized precipitation and evapotranspiration index (SPEI): The SPEI is a drought index based on the climatic water balance (CWB) approach, which combines precipitation and potential evapotranspiration (PET) (Serrano 2010) as input values, wherein CWB is defined as follows;

$$CWB_i = R_i - PETi$$

R denotes rainfall and i denotes the monthly counter, which delivers a monthly water excess or shortage measure. The use of PET methods significantly impacts the calculation of the drought index. The SPEI index was computed using the Hargreaves method (Beguria et al 2013). The SPEI effectively identified significant historical droughts and is regarded as a reliable index for detecting drought events (Table 1). The negative SPEI value signifies a drought period, while a positive value represents a period of increased precipitation.

Spatial-temporal trend analysis: Hydro-meteorological data is typically non-parametric statistical tools. Therefore, the Mann-Kendall test and Sen's slope method were applied to assess the direction and magnitude of trends (Kendall 1975, Sen 1968 and Mann 1945).

Total drought duration frequency: To analyze drought sensitivity, drought frequency was identified for all drought events with SPEI less than zero over the entire study period Ni (Wang et al 2014).

$$\text{Drought frequency} = \frac{n_i}{N_i} \times 100$$

where n_i is the number of drought events and Ni is the total number of months in the time series (1966-2017). The frequency results for various drought classes were assessed with varying intensities based on Table 1.

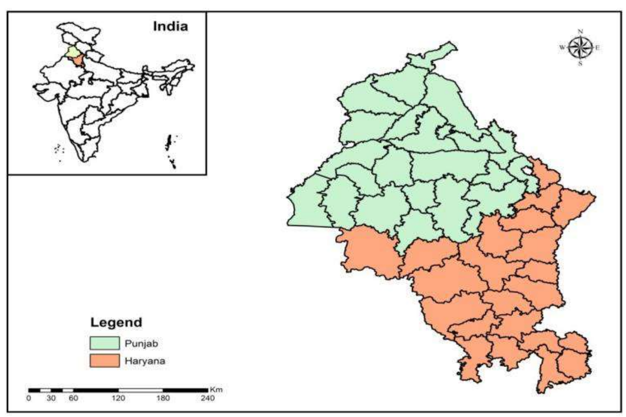
Table 1. Classification of drought by SPEI values

SPEI	Interpretation
≥ 1.00	Severe wet
0.5 to 1.0	Moderately wet
0 to 0.5	Near normal
-0.5 to 0	Light drought
-1.00 to -0.5	Moderate drought
< -1.0	Severe drought

Source: Serrano et al 2010

RESULTS AND DISCUSSION

Spatio-temporal pattern of rainfall: Rainfall in Punjab showed a high variation over the years with a decreasing trend in the last decade (Fig. 1). Hoshiarpur (1017.22 mm) and Gurdaspur (957.86 mm) recorded the highest average annual rainfall between 1966 and 2017, while Ferozepur (371.52 mm) and Bathinda received the least (395.23 mm) respectively. The average monthly rainfall follows a similar pattern throughout the year. Hoshiarpur shows the highest monthly average rainfall in July and August, followed by Gurdaspur in July and August, and Rupnagar had higher rainfall in June and October. The monthly average rainfall in Ferozepur and Bathinda was lowest in November, July and August received the most rainfall, while November and October received the least in Punjab. There has been no consistent rainfall over the last five decades. Kingra et al (2017) found a similar result.



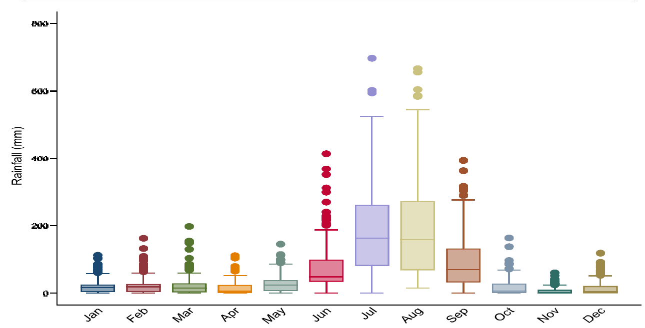


Fig. 1. Box plot of monthly rainfall in Punjab

During the growing period of rice (June-October), Hoshiarpur received the most rainfall (805.03 mm), followed by Gurdaspur, while Ferozepur Bathinda received the least rain. During this season, the state received 555.56 mm of rain. Ferozepur district exhibited a declining trend in annual rainfall, with a similar pattern observed in Gurdaspur for June-October rainfall. Significant monthly decreases in rainfall were also recorded in July for four districts in Punjab (Bathinda, Ferozepur, Gurdaspur and Sangrur) and in August for three districts (Amritsar, Bathinda and Ferozepur). The highest significant increasing trend was observed during April, where seven districts namely Amritsar, Bathinda, Hoshiarpur, Jalandhar, Kapurthala, Ludhiana, and Patiala show an increasing trend.Saxena and Mathur (2017) observed a non-significant decrease in monsoon rainfall and an increase in post-monsoon rainfall in North West India. This trend raises concerns for Kharif and rainfed Rabi crops that depend on stored soil moisture. A similar finding was observed by Chauhan et al (2022).

During the growing period of wheat (November-March), Gurdaspur received the most rainfall (170.02 mm), followed by Hoshiarpur. The district of Ferozepur received the least rainfall (48.2 mm), followed by Bathinda and the state received rainfall of (102.11 mm). No significant trends were observed for rainfall in all months except April, July and August. The monthly, seasonal, and annual precipitation patterns analysis revealed that significant changes were largely concentrated in Amritsar, Bathinda, Ferozepur, and Gurdaspur districts. Kumar and Sidana (2019) reported a decline in rainfall across all agroclimatic zones of Punjab. Their study highlighted that between 1986 and 2016, rainfall during the rice-growing season decreased by 208 mm, indicating a substantial reduction of 6.92% annually. In contrast, rainfall during the wheat-growing season saw a smaller, non-significant decline of 20 mm or 0.68% per year. Krishan et al (2015) observed an overall increase in annual and growing season rainfall across all districts, except during the winter season in Hoshiarpur, Kapurthala, Amritsar, Gurdaspur, Jalandhar, Ludhiana, Rupnagar, and Patiala. However, the extent of these trends varied from district to district. Consistent results show that in Bathinda, both the annual and monsoon rainfall have exhibited a decreasing trend, whereas, in Ludhiana, the yearly and monsoon rainfall have shown an increasing trend (Gill and Kukal 2017). Rainfall in Haryana also showed a similar trend of high variation over the years with a decreasing trend in the last decade (Fig. 2). Results revealed that the average annual rainfall received in the districts of Ambala (1146.9 mm) and Karnal (672.31 mm) was the highest, while Hisar (387.68 mm) and Mahendragarh received the least (536.69 mm). Ambala had the highest monthly average rainfall in August and July, followed by Karnal in August and July. Mahendragarh received higher rainfall after Ambala in May. The monthly average rainfall in Mahendragarh and Hisar was lowest in November. August and July received the most rainfall, while November and December received the least in Haryana.

During the growing period of rice (June-October), Ambala received the most rainfall (953.39 mm), followed by Karnal (563.82 mm), while Hisar (319.11 mm) and Jind (411.98 mm) received the least rain. During this season, the state received 520.2 mm of rain. Furthermore, the study revealed that during the wheat growing period (November- March), Ambala received the most rainfall, followed by Jind while, the district of Gurgaon received the least rainfall, followed by Mahendragarh, and the state received rainfall of 63.75 mm. Abhilash et al (2020) also found that all locations have shown a general decreasing trend in rainfall behavior in recent times, with the variability of rainfall being greater in western Haryana than in eastern Haryana.

Trend of changes in temperature: The temperature (maximum, minimum, and average) trend of June-October and November-March in both states showed a similar trend. Significant monthly decreasing trends in maximum temperature were observed in all the districts of Punjab except Amritsar and Gurdaspur in January. No significant trend was detected in other months and seasons except in January. Singh et al (2022) also reported no significant trend in maximum temperature. The average minimum temperatures during the monthly and crop-growing seasons exhibited an upward trend across all districts of Punjab in January, February, March, July, August, September, October, November, and December. Significant increasing trends in monthly average minimum temperature were also observed in two districts (Bathinda and Ferozepur) in April and eight districts (Bathinda, Ferozepur, Hoshiarpur, Jalandhar, Ludhiana, Patiala, Rupnagar, and Sangrur) in May. No significant trend was detected in June in all the districts.

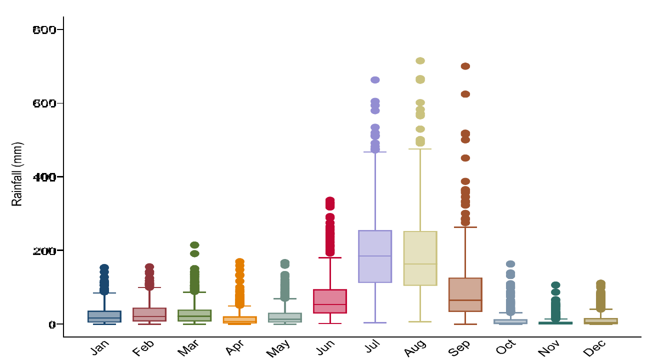


Fig. 2. Box plot of monthly rainfall in Haryana

Singh (2018) also reported that a decade-wise analysis using the Mann-Kendall test and Sen's slope estimator revealed a significant increase in all regions, with the rate of increase in the three regions of the state being approximately 0.05°C per year. The study observed that the minimum temperature during June–October and November–March in both states showed an increasing trend over the years.

In January, the average monthly maximum temperature showed a significant decreasing trend across all districts of Haryana. Conversely, a significant increasing trend was observed in five districts (Ambala, Gurgaon, Karnal, Mahendragarh, and Rohtak) during August. No significant trends were identified for the other months and growing seasons, except for January and August. Meanwhile, the average minimum temperatures in both monthly and crop-growing seasons showed an increasing trend in all districts of Haryana for February, March, May, August, September, November, and December. Significant increasing trends in monthly average minimum temperature were also observed in January in all the districts except Mahendragarh. Furthermore, the Mahendragarh district showed no significant trend in April, July, and October while other districts showed an increasingly significant trend. However, Mahendragarh is the only district exhibiting a significant increasing trend in June, while no significant trends were found in the other districts. Umer et al (2014) observed that there has been an increase in the variation of maximum and minimum temperatures, along with a decrease in the number of rainy days, which has impacted wheat production in Haryana. Shalo et al (2016) also found a consistent result in the case of trend analysis of average minimum temperature showing a significant increasing trend with a 95% confidence level between 1969 and 2010 in Rohtak.

M-K test and Sen's slope of district-wise drought : Timescales usually vary from 1-48 months. Longer timescales (from 12 to 48 months) reflect the drought index for hydrology, whereas shorter timescales (from 1 to 6 months) indicate the drought index for agricultural practices. SPEI was calculated at 1, 5, and 12 months to examine the consistency of moisture conditions across all districts. The region's growing season for rice is SPEI-5 October, while that of wheat is SPEI-5 March. Additionally, a time scale of 1 month (SPEI 1) was estimated to correlate the drought with the crop's critical water requirement stage. December 12 months' (SPEI 12) timescale was also estimated to track drought at a year (Table 2).

Punjab experienced the most severe drought in 1987, 2002, and 2016.The monthly SPEI-1 (Table 2) shows a

Table 2. M-K test and Sen's slope of district-wise drought (SPEI) of Punjab

District		SPEI-1					SPEI-5	SPEI-1					SPEI-5 March	SPEI-12 December
	Test	June	July	August	September	October	October	November	December	January	Fevruary	March		
Amritsar	Z	1.15	-0.84	-1.88*	0.52	-1.05	-0.52	-2.30**	-1.05	0.73	0.42	-1.05	-0.52	-1.47
	Slope	0.01	-0.01	-0.01	0.01	-0.01	0.00	-0.02	-0.01	0.01	0.00	-0.01	-0.01	-0.01
Bathinda	Z	1.05	-2.09**	-1.99**	0.52	-3.14***	-1.47	-3.14***	-1.15	1.05	-1.05	-1.36	-1.78*	-2.41**
	Slope	0.01	-0.02	-0.02	0.00	-0.03	-0.01	-0.03	0.00	0.01	-0.01	-0.01	-0.02	-0.02
Ferozepur	Z	0.84	-2.09**	-1.99**	0.00	-1.99**	-1.67*	-3.14***	-1.05	0.52	-0.11	-1.36	-1.99**	-2.51**
	Slope	0.01	-0.02	-0.02	0.00	-0.02	-0.02	-0.03	-0.01	0.01	-0.01	-0.01	-0.02	-0.03
Gurdaspur	Z	-0.31	-2.19**	-1.15	0.31	-0.73	-1.88*	-2.62***	-0.73	0.00	0.31	-1.05	-1.05	-1.67*
	Slope	0.00	-0.02	-0.01	0.00	-0.01	-0.02	-0.02	-0.01	0.00	0.01	-0.01	-0.01	-0.02
Hoshiarpur	Z	0.31	-1.36	-1.05	-0.11	-0.94	-1.26	-2.83***	-0.52	-0.21	0.11	-0.42	-1.05	-1.36
	Slope	0.00	-0.01	-0.01	0.00	-0.01	-0.01	0.00	0.00	0.00	0.00	-0.01	-0.01	-0.01
Jalandhar	Z	0.73	-0.21	-1.05	1.05	-0.94	0.00	-3.14***	-0.52	1.05	0.00	-0.84	-0.84	-0.52
	Slope	0.01	0.00	0.00	0.01	-0.01	0.00	-0.03	0.00	0.01	0.00	0.00	-0.01	-0.01
Kapurthala	Z	1.05	0.31	-0.52	1.05	-0.63	0.42	-3.14***	-0.52	0.84	0.42	-0.73	-0.31	0.21
	Slope	0.01	0.00	0.00	0.01	-0.01	0.01	-0.03	0.00	0.01	0.01	0.00	0.00	0.00
Ludhiana	Z	0.31	-0.21	-0.73	-0.73	-1.05	-0.31	-3.14***	-0.73	0.73	-0.31	-0.73	-1.05	-0.52
	Slope	0.01	0.00	-0.01	-0.01	-0.01	0.00	-0.03	0.00	0.01	0.00	-0.01	-0.01	-0.01
Patiala	Z	0.84	-1.05	-0.84	1.05	-1.47	-0.31	-2.93***	-1.05	0.84	-0.11	-0.42	-0.73	-0.73
	Slope	0.01	-0.01	-0.01	0.01	-0.01	0.00	-0.02	0.00	0.01	0.00	0.00	-0.01	-0.01
Rupnagar	Z	0.52	0.52	-0.63	1.05	-0.31	0.11	-3.14***	-0.21	0.73	0.52	-0.52	-0.42	-0.11
	Slope	0.00	0.01	0.00	0.01	0.00	0.00	-0.02	0.00	0.01	0.00	0.00	0.00	-0.01
Sangrur	Z	0.84	-1.78*	-1.67*	0.84	-1.78*	-1.15	-3.45***	-0.31	0.84	-0.31	-1.05	-1.57	-1.78*
	Slope	0.01	-0.02	-0.02	0.01	-0.01	-0.01	-0.03	0.00	0.01	0.00	-0.01	-0.02	-0.01

***, ** and * indicate significance at the 1%, 5% and 10%, respectively significant decreasing trend in the districts of Amritsar (August), Bathinda (July, August, and October), Ferozepur (July and August), Gurdaspur (July), Sangrur (July and August), and November showed a decreasing trend in all the districts of Punjab. SPEI-5 October also showed a significantly decreasing trend in the Gurdaspur district, while the rest of the districts showed no significant trend. Moreover, Bathinda and Ferozepur are the only districts that showed a significantly decreasing trend for SPEI-5 March.SPEI-12 values dropped in Patiala, Gurdaspur, and Ludhiana in Punjab.

The decreasing trend was observed in SPEI-1 in all the districts of Haryana (Table 3). Ambala (October), Gurgaon (August and October), Hisar (July and October), Jind (July), Karnal (July, August, and October), Mahendragarh (August and October) and Rohtak (July, August, and October), and all the districts in Novembershowed a decreasing trend. SPEI-5 October shows a significant decreasing trend in Ambala, Gurgaon, Karnal, and Rohtak, and SPEI-5 March in Hisar and Rohtak. Haryana also experienced the most severe droughts in 1987, 2002, and 2016 with SPEI-12 December values dropped in Gurgaon, Jind, and Rohtak in 1987, in Gurgaon, Hisar, and Mahendragarh in 2002, and Karnal in 2016.Gupta et al (2022) reported that drought has recently intensified in several regions of the northern Indian plains, raising worries about its effects on agricultural productivity, particularly crop yields.

Spatial pattern of frequency and severity of drought: SPEI-5 October drought occurrence showed a frequency of about 28-38% of moderate and severe drought combined in Punjab (Table 4). Ferozepur experienced the highest frequency of severe drought, accounting for 21.15%, and SPEI-5 October had a frequency of about 32-38% of moderate and severe drought combined. SPEI-5 March drought occurrence showed a frequency of about 26-36% of moderate and severe drought combined (Table 6). Ludhiana

Table 3. M-K test and Sen's slope of district-wise drought (SPEI) of Haryana

District		SPEI-1					SPEI-5	SPEI-1					SPEI-5	SPEI-12
	Test	June	July	August	September	October	October	November	December	January	Fevruary	March	March	December
Ambala	Z	-1.26	-0.84	-1.47	0.73	-1.99***	-1.88*	-2.93***	-1.36	0.31	-0.11	-0.42	-1.15	-2.09**
	Slope	-0.01	-0.01	-0.01	0.01	-0.02	-0.02	-0.03	-0.01	0.00	0.00	0.00	-0.01	-0.02
Gurgaon	Z	0.11	-1.05	-2.09**	0.21	-2.19**	-2.09**	-2.30**	-1.88*	0.63	-0.11	-1.05	-1.57	-2.72***
	Slope	0.00	-0.01	-0.02	0.00	-0.02	-0.02	-0.02	-0.01	0.01	0.00	-0.01	-0.01	-0.02
Hisar	Z	0.63	-1.78*	-1.57	0.42	-2.83***	-1.26	-2.93***	-1.57	0.31	-0.63	-0.94	-2.09**	-2.09**
	Slope	0.01	-0.02	-0.02	0.00	-0.02	-0.01	-0.03	-0.01	0.00	-0.01	-0.01	-0.02	-0.02
Jind	Z	0.52	-1.67*	-1.36	0.63	-1.47	-0.94	-2.72***	-1.47	1.15	0.11	-1.05	-1.26	-1.47
	Slope	0.01	-0.02	-0.02	0.01	-0.01	-0.01	-0.02	-0.01	0.01	0.00	-0.01	-0.01	-0.01
Karnal	Z	0.42	-2.51**	-2.62**	0.63	-1.88*	-2.93***	-2.93***	-2.09*	0.84	-0.11	-0.84	-1.05	-3.14***
	Slope	0.01	-0.02	-0.02	0.01	-0.02	-0.03	-0.02	-0.01	0.01	0.00	-0.01	-0.01	-0.03
Mahendra garh	Z	0.63	-1.67	-1.88*	-0.11	-2.30**	-1.36	-2.19**	-1.57	-0.11	0.63	-0.84	-0.84	-1.88*
	Slope	0.01	-0.02	-0.02	0.00	-0.02	-0.01	-0.02	-0.01	0.00	0.01	-0.01	-0.01	-0.02
Rohtak	Z	0.11	-2.30**	-2.51**	0.00	-2.41**	-2.83***	-2.62***	-1.78*	-0.11	-0.21	-1.05	-1.78*	-3.14***
	Slope	0.00	-0.02	-0.03	0.00	-0.02	-0.03	-0.02	-0.01	0.00	0.00	-0.01	-0.02	-0.03

***, ** and * indicate significance at the 1%, 5% and 10%, respectively

Table 4. Drought frequency of SPEI-5 October in Punjab

SPEI value	Interpretation	Amritsar	Bathinda	Ferozepur	Gurdaspur	Hoshiarpur	Jalandhar	Kapurthala	Ludhiana	Patiala	Rupnagar	Sangrur
1.0+	Severe wet	19.23	17.31	23.08	13.46	15.38	15.38	17.31	7.69	11.54	19.23	17.31
0.5 to 1.0	Moderately wet	15.38	13.46	15.38	23.08	19.23	15.38	13.46	26.92	15.38	11.54	15.38
0 to 0.5	Near normal	15.38	21.15	11.54	17.31	15.38	21.15	21.15	19.23	23.08	19.23	21.15
-0.5 to 0	Light drought	13.46	19.23	13.46	7.69	15.38	19.23	17.31	15.38	19.23	13.46	7.69
-1.0 to -0.5	Moderate drought	21.15	11.54	15.38	19.23	17.31	9.62	15.38	15.38	15.38	19.23	26.92
< -1.0	Severe drought	15.38	17.31	21.15	19.23	17.31	19.23	15.38	15.38	15.38	17.31	11.54

Table 5. Drought frequency of SPEI-5 October of Haryana

SPEI value	Interpretation	Ambala	Gurgaon	Hissar	Jind	Karnal	Mahendragarh	Rohtak
1.0+	Severe wet	19.23	15.38	17.31	13.46	11.54	15.38	21.15
0.5 to 1.0	Moderately wet	11.54	17.31	17.31	17.31	26.92	13.46	9.62
0 to 0.5	Near normal	23.08	17.31	11.54	21.15	13.46	23.08	17.31
-0.5 to 0	Light drought	9.62	15.38	21.15	15.38	9.62	13.46	21.15
-1.0 to -0.5	Moderate drought	21.15	21.15	17.31	19.23	23.08	17.31	17.31
< -1.0	Severe drought	15.38	13.46	15.38	13.46	15.38	17.31	13.46

Table 6. Drought frequency timescale SPEI-5 March of Punjab

SPEI value	Interpretation	Amritsar	Bathinda	Ferozepur	Gurdaspur	Hoshiarpur	Jalandhar	Kapurthala	Ludhiana	Patiala	Rupnagar	Sangrur
1.0+	Severe wet	19.23	21.15	17.31	19.23	25	23.08	23.08	15.38	17.31	15.38	19.23
0.5 to 1.0	Moderately wet	15.38	11.54	17.31	17.31	7.69	5.77	5.77	13.46	13.46	9.62	11.54
0 to 0.5	Near normal	15.38	17.31	15.38	9.62	15.38	15.38	17.31	25	17.31	28.85	15.38
-0.5 to 0	Light drought	13.46	23.08	15.38	19.23	19.23	25	21.15	15.38	19.23	19.23	21.15
-1.0 to -0.5	Moderate drought	21.15	11.54	17.31	19.23	11.54	13.46	17.31	7.69	19.23	5.77	17.31
< -1.0	Severe drought	15.38	15.38	17.31	15.38	21.15	17.31	15.38	23.08	13.46	21.15	15.38

Table 7. Drought frequency of SPEI-5 March of Haryana

SPEI value	Interpretation	Ambala	Gurgaon	Hissar	Jind	Karnal	Mahendragarh	Rohtak
1.0+	Severe wet	23.08	17.31	19.23	19.23	19.23	17.31	15.38
0.5 to 1.0	Moderately wet	7.69	11.54	15.38	11.54	13.46	19.23	17.31
0 to 0.5	Near Normal	17.31	23.08	13.46	15.38	13.46	9.62	17.31
-0.5 to 0	Light drought	15.38	19.23	23.08	25	21.15	25	21.15
-1.0 to -0.5	Moderate drought	21.15	15.38	13.46	13.46	15.38	9.62	11.54
< -1.0	Severe drought	15.38	13.46	15.38	15.38	17.31	19.23	17.31

recorded the highest frequency of severe drought, at approximately 23%. SPEI-5 March showed a frequency of about 28-36% of moderate to severe drought combined. While in Haryana, extreme dryness was observed in Mahendragarh district with 5.77% (Table 5) and SPEI-5 October a frequency of about 32-38% of moderate and severe drought combined. SPEI-5 March showed a frequency of about 28-36% of moderate to severe drought combined (Table 7).

CONCLUSIONS

The study provides a comprehensive assessment of drought characteristics using standardized drought indices, employing the SPEI across various monthly timescales in Punjab and Haryana. Significant monthly decreasing trends of rainfall were observed in four districts of Punjab (Bathinda, Ferozepur, Gurdaspur, and Sangrur) in July, and three districts (Amritsar, Bathinda, and Ferozepur) in August. Significant monthly decreasing rainfall trends were also observed in five districts of Haryana (Gurgaon, Jind, Karnal, Mahendragarh, and Rohtak) in July, three districts (Gurgaon, Mahendragarh, and Rohtak) in August. The study observed that the minimum temperature during June-October and November-March in both states showed an increasing trend over the years. The highest frequency of severe drought was observed in Ludhiana and Mahendragarh. This research provides valuable insights for agricultural researchers, policymakers, and planners to create various irrigation and water management strategies suited to various climate change scenarios in the region. Policymakers must make efforts to adopt sustainable approaches that maximize the efficiency of water delivery and usage, such as rainwater harvesting, wastewater management, drip irrigation, and the use of recycled water.

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Assessment of Soil Physico-Chemical Properties after Conversion of Sand Dunes into Arable Land in Hot Semi-Arid Climatic Conditions of Punjab

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***Abstract*:** The study aimed to assess changes in soil organic carbon (SOC) stock and physico-chemical properties of soil in semi-arid regions after 30 years of continuous rice-wheat cultivation. The SOC stock in the surface soil enhanced by 279% and in the subsurface soil by 54% compared to the SOC stock in the sand dunes. Furthermore, in the topsoil, prolonged cultivation of the rice-wheat system resulted in an increase of 84%, 132%, 121%, and 377% in the levels of sulphur, zinc, copper, and iron, respectively. This enhancement was also evident in the subsoil, with respective increases of 35%, 81%, 6%, and 266% in sulphur, zinc, copper, and iron content. However, continuous cultivation of rice-wheat system resulted in depletion of available manganese by 62% in topsoil despite of the positive impacts of continuous rice-wheat cultivation. Therefore, further research is needed to study the changes in microbial flora, an important soil quality indicator, in order to gain more comprehensive and relevant information about the effects of continuous cultivation of different cropping systems on soil health.

Keywords: Sand dune, SOC, Rice-wheat, Continuous cultivation

Understanding the formation and persistence of soil organic matter (SOM) is crucial for maintaining the sustainability of arable soils (Lal 2009). Soil organic carbon (SOC) is a vital indicator of soil quality and contributes to enhancing microbial processes, cation exchange capacity, water holding capacity, and infiltration rate through the soil profile. It also reduces soil bulk density and cohesion, ultimately enhancing crop productivity (Schillaci et al 2017). Recent attention has been focused on understanding the controls of terrestrial carbon storage due to concerns over rising atmospheric CO_2 concentration and its implications for global climate change. Soil organic carbon (SOC) is particularly important as it represents the largest stock of terrestrial carbon and has the potential to act as either a CO_2 source or sink (Moharana et al 2021). Arid and semi-arid lands are characterized by higher temperatures, low and irregular precipitation, low surface water availability, marginal soil health, and limited vegetation diversity (Acosta-Rangel et al 2019). Despite their low soil organic carbon (SOC) content, these areas store 16% of the total carbon in the soil globally. Long-term studies across various land use and management systems have demonstrated the potential for SOC sequestration in cultivated lands (Ghimire et al., 2015)eroded lands (Shukla and Lal, 2005a), and severely disturbed and reclaimed mine-lands (Nyamadzawo et al., 2008) through improved management practices. Fixing atmospheric carbon in soils (soil carbon sequestration) is the key to enhancing soil quality and curbing global warming. The rice-wheat cropping system in South Asia accounts for 27 and 16% of global rice and wheat production, respectively, and sustains more than 129 million farmers, most of whom are smallholders. However, rice and wheat yield trends in this region have slowed or stagnated due to the impacts of climate change, and these negative impacts are projected to worsen over the coming decades (Ishtiaque et al 2024). The impact of conversion of sand dunes to stabilized cultivated arable land under semi-arid condition of Indo Gangetic plain in surface and sub-surface soil is very limited. Thus, there is strong need to assess the impact of land use change on SOC stock and soil physico-chemical properties of *Inceptisols* in the IGP of India, which may help us to better understand the effect of long-term cultivation of rice-wheat system on soil quality and global climate change. Thus, the main objective of the current study was to analyse the long-term impact of conversion of sand dunes to cultivable arable land on soil organic carbon stock.

MATERIAL AND METHODS

Site description: The research was conducted in the Faridkot district, situated in the southwestern region of Punjab, India (30°21′59” to 30° 49′ 52″ N and 74°28′12″ to 75°03′22″ E). Encompassing a total area of 1418.60 km2, the district experiences a predominantly semi-arid climate characterized by intense summers, a brief monsoon season, and cold winters. The cold season spans from November to March, followed by the summer season lasting until the end of June. The period from July to mid-September constitutes the southwest monsoon season. The district records an average annual rainfall of 449 mm, with approximately 78 percent occurring during the monsoon months of July to September. The average elevation of the district is 196 meters and t is situated on the Punjab Plains, forming part of the greater Satluj Ganga plain in a macro-regional context. The area generally exhibits a low-lying flat topography that slopes towards the southwest, with a few linear depressions occupied by paleo-bluff and paleo channels near Pakka and southeast of Kamiyana Villages, as well as sand dunes concentrated in the northwestern and southern parts of the study area. Due to the exceptionally flat topography, there is not much of a developed drainage system. The soil classes found in the study region were loams, loamy sand, sandy to fine sandy loams, and silty loam, with loam sand as a predominant class within the study area.

Soil sampling: The soil samples from surface (0-15 cm) and sub-surface (15-30 cm) were collected from 20 different sites under two different land use patterns viz. sand dunes and already stabilized cultivable land under rice-wheat crop rotationduring April 2022. The geographical coordinates of the sampling points were recorded using a handheld geographical positioning system. Soils were sampled from each depth at 8 random points on each sampling site by a soil sampling auger. The sampled soils were composited and were treated as one. The total 80 soil samples (40 surface and 40 sub-surface soil samples of both sand dunes and rice-wheat crop rotation) was brought into the laboratory The samples were air dried, grinded and sieved with a 2.0 mm sieve and stored for analysis.The soil sample core of surface and sub-surface soil was also sampled from the field to calculate the bulk density and calculate the total porosity of the soil.

Soil analysis: Walkley Black oxidizable soil organic carbon (WB-SOC) was analyzed by oxidizing 2 g soil with potassium dichromate in the presence of concentrated sulfuric acid (Walkley and Black, 1934). The well-established, coremethod was used to measure the bulk density of the surface and subsurface soil (Bandyopadhyay et al 2012). The particle density of both surface and surface soil was assumed to be 2.65 Mg m^{-3} to further calculate the total pore space of the soil (Eq.1).

$$Total\ soil\ porosity(\%) = \left[1 - \left(\frac{\rho b}{\rho s}\right)\right] * 100$$

Where, $\frac{\rho b}{\rho s}$= $bulkdensity/\ particle\ density$ [1]

The plant available sulfur in soil was analyzed turbidimetrically at 420nm wavelength on spectrophotometer (Chesnin and Yenin 1951). Thecationic micronutrients (Zn, Fe,Cu and Mn) were analyzed on ICP-OES following the procedure of Lindsay and Norvell 1978.The SOC stock of surface and sub-surface soil was calculated (Eq. 2) from respective soil organic carbon concentration and soil bulk density.

C stocks (Mg ha^{-1})=SOC (%) × Bulk density (Mg m^{-3})× soil depth (cm) [2]

Data analysis: The descriptive statistics, correlation and linear regression for soil physico-chemical properties were evaluated at significance level of $p<0.005$ and $p<0.001$usingSPSS 25.0 Software SPSS Inc., Chicago, IL, USA)

RESULTS AND DISCUSSION

Descriptive statistic: In surface soil the SOC stock in both sand dune and rice-wheat cropping system was highly variable and ranged from1.13 to 4.08 Mg ha and 6.14 to 13.40 Mg ha^{-1}, respectively (Table 1, 2). The SOC stock in rice-wheat system in subsurface soil ranged from 3.69 to 10.63 Mg ha^{-1} and averagely decreased by 27 % incomparison to surfacesoil which might be accredited to greater root biomass addition in surface soil owing to shallow root system of paddy (Moharana et al 2021). The average decrease in soil organic carbon (SOC) stock ranged from 26 to 41% in sub-surface soil compared to surface soil in a rice-based cropping system, as reported by Meetei et al (2020).

Bulk density and total soil porosity: In the topsoil of sand dunes, the bulk density ranged from 1.55 to 1.70 Mg m-3, and the total soil porosity ranged from 35.90% to 41.70%. In contrast, the topsoil under a rice-wheat system exhibited a bulk density ranging from 1.49 to 1.65 Mg m^{-3} and a total soil porosity ranging from 37.85 to 43.83% (Table 1). Over time, the cultivation of rice and wheat resulted in a 3% reduction in soil bulk density in the topsoil and a 15% increase in the subsurface soil compared to sand dunes. The subsurface compaction beneath the puddled zone, attributed to aggregate disruption, has emerged as a significant constraint for sustainable productivity in the Indo-Gangetic Plain (IGP) (Singh et al 2018). The improvement of total soil porosity in top soil under rice-wheat system was due to decrease in bulk density and increase is surface soil organic carbon content. The significant positive correlation existsbetween total soil porosity and SOC(Fukumasu et al 2022) and these relations are well established at field scale (Jarvis et al 2017).

Sulphur and cationic micronutrient: The long-term cultivation of rice-wheat for 30 years has enhanced the sulphur, zinc, copper and iron by 84, 132, 121 and 377% in surface soil and 35,81,6and 266% in subsurface soil respectively. Beside the positive impact of 30-year long term cultivation of rice-wheat, manganese (Mn) content in surface soil reduced by 62% but enhanced by 306% in subsurface soil (Table 1, 2). The intensive agriculture and skewness toward high-analysis fertilizers have gradually depleted the soil of available micronutrients in the surface soil. Furthermore, continuous intensive rice-wheat cultivation leads to the formation of subsurface hardpan, thereby reducing DTPA-extractable Mn (Balloli et al 2000). The continuous flooding in paddy might have led to the leaching of Mn which resulted in high available Mn content in subsurface soil with respect to the surface soil (Narender et al 2018). The substantial variability within the study area could be

Table 1. Descriptive statistics for surface soil (0-15 cm)of sand dune and rice-wheat system in the south-western district of Punjab

Major land use	Soil physico-chemical properties	Central tendency			Dispersion					Distribution	
		Mean	Median	Mode	Minimum	Maximum	SE	SD	CV (%)	Skewness	Kurtosis
Sand Dune	SOC stock ($Mgha^{-1}$)	2.65	3.03	1.13	1.13	4.08	0.47	1.15	43.30	-0.45	-1.33
	Bulk density (Mgm^{-3})	1.62	1.62	1.55	1.55	1.70	0.03	0.06	4.02	0.14	-2.18
	Total Porosity (%)	38.80	38.50	36.20	35.90	41.70	0.98	2.40	6.20	0.24	-1.74
	Zn (ppm)	0.51	0.50	0.31	0.31	0.77	0.08	0.19	36.70	0.25	-2.17
	Cu (ppm)	0.35	0.36	0.24	0.24	0.45	0.03	0.07	20.70	-0.17	0.42
	Fe (ppm)	3.96	3.30	2.11	2.11	7.05	0.81	1.97	49.80	0.91	-0.76
	Mn (ppm)	2.26	2.37	0.83	0.83	3.84	0.42	1.04	46.10	0.42	1.04
	S (ppm)	14.86	14.72	5.28	5.28	27.59	3.00	7.36	49.50	0.85	2.08
Rice-wheat	SOC stock ($Mg\ ha^{-1}$)	8.27	7.29	6.14	6.14	13.40	1.14	2.80	33.90	1.52	1.74
	Bulk density ($Mg\ m^{-3}$)	1.58	1.59	1.60	1.49	1.65	0.02	0.05	3.30	-0.90	2.16
	Total Porosity (%)	40.39	40.33	37.85	37.85	43.83	0.80	1.96	4.90	0.92	2.36
	Zn (ppm)	1.19	0.95	0.10	0.10	3.49	0.50	1.24	1.19	1.59	2.79
	Cu (ppm)	0.77	0.81	0.50	0.50	0.99	0.07	0.18	0.77	-0.55	-0.46
	Fe (ppm)	18.89	15.26	4.11	4.11	34.56	5.09	12.48	18.89	0.48	-1.62
	Mn (ppm)	0.86	0.57	0.28	0.28	2.41	0.33	0.80	0.86	1.94	3.90
	S (ppm)	27.35	28.36	14.29	14.29	38.64	3.43	8.40	27.35	-0.38	0.25

Table 2. Descriptive statistics for sub-surface (15-30cm) of sand dune and rice-wheat system in the south-western district of Punjab

Major land use	Soil physico-chemical properties	Central tendency			Dispersion					Distribution	
		Mean	Median	Mode	Minimum	Maximum	SE	SD	CV (%)	Skewness	Kurtosis
Sand Dune	SOC stock ($Mg\ ha^{-1}$)	2.74	2.67	1.14	1.14	4.56	0.51	1.25	45.70	0.24	-0.96
	Bulk density ($Mg\ m^{-3}$)	1.58	1.63	1.40	1.40	1.69	0.05	0.12	7.80	-0.85	-1.22
	Total porosity (%)	40.40	38.90	36.20	36.21	47.27	1.89	4.63	11.50	0.72	-1.41
	Zn (ppm)	0.71	0.32	0.30	0.28	2.42	0.35	0.85	35.00	2.33	5.49
	Cu (ppm)	0.57	0.40	0.30	0.30	1.05	0.13	0.32	56.40	0.98	-1.38
	Fe (ppm)	4.19	3.50	2.16	2.16	9.36	1.09	2.67	63.70	1.92	4.01
	Mn (ppm)	0.68	0.74	0.34	0.34	0.91	0.08	0.20	29.40	-1.01	1.02
	S(ppm)	19.42	14.87	6.69	6.69	45.57	6.15	15.08	77.60	1.21	0.89
Rice-wheat	SOC stock ($Mg\ ha^{-1}$)	6.34	5.91	3.69	3.69	10.63	1.02	2.50	39.50	1.04	1.01
	Bulk density ($Mg\ m^{-3}$)	1.81	1.81	1.66	1.66	1.94	0.04	0.10	5.30	-0.22	0.38
	Total Porosity (%)	31.81	31.62	26.85	26.85	37.52	1.49	3.64	11.40	0.37	0.56
	Zn (ppm)	1.29	1.30	0.64	0.64	1.90	0.20	0.49	38.30	-0.094	-1.73
	Cu (ppm)	0.60	0.60	0.32	0.32	0.98	0.10	0.25	41.80	0.369	-0.88
	Fe (ppm)	15.32	8.79	2.26	2.26	41.43	6.43	15.76	40.20	1.12	-0.08
	Mn (ppm)	2.76	2.09	0.86	0.86	5.94	0.88	2.15	77.70	0.71	-1.44
	S (ppm)	26.21	21.63	18.98	18.98	40.07	3.59	8.79	33.50	1.09	-0.84

attributed to the implementation of diverse soil management practices, encompassing disparities in fertilizer application and other agricultural management practices (Behera et al 2016). The continuous paddy cultivation for 15 years and soils with high SOC content resulted in high soil total and available sulphur pools of the soil (Zhou et al 2024). The diminished level of soil organic carbon (SOC) within sand dunes can be attributed to limited vegetation cover. The exposure of soils to intense solar radiation leads to the oxidation of SOC (Pandey et al 2010).

Correlation and Linear regression between SOC stock, BD, total soil porosity, sulphur and cationic micronutrients: The analysis revealed negative correlation between soil organic carbon (SOC) stock and bulk density in both surface soil (-0.513) and sub-surface soil (-0.649), regardless of the land use pattern. This correlation was statistically significant (Table 3) whereas the change in SOC stock could explain 27% and 21% variation in bulk density of surface and subsurface soil, respectively (Fig. 1A) and these results are in agreement with results of Yu et al (2014). Changes in land use invariably result in alterations to soil physical and chemical properties. (Sun et al 2011). The increase in soil porosity and significant positive correlation coefficient of 0.345 and 0.549 for surface and subsurface soil, respectively with SOC stock explained the decrease in bulk density under continuous rice-wheat cultivation for 30

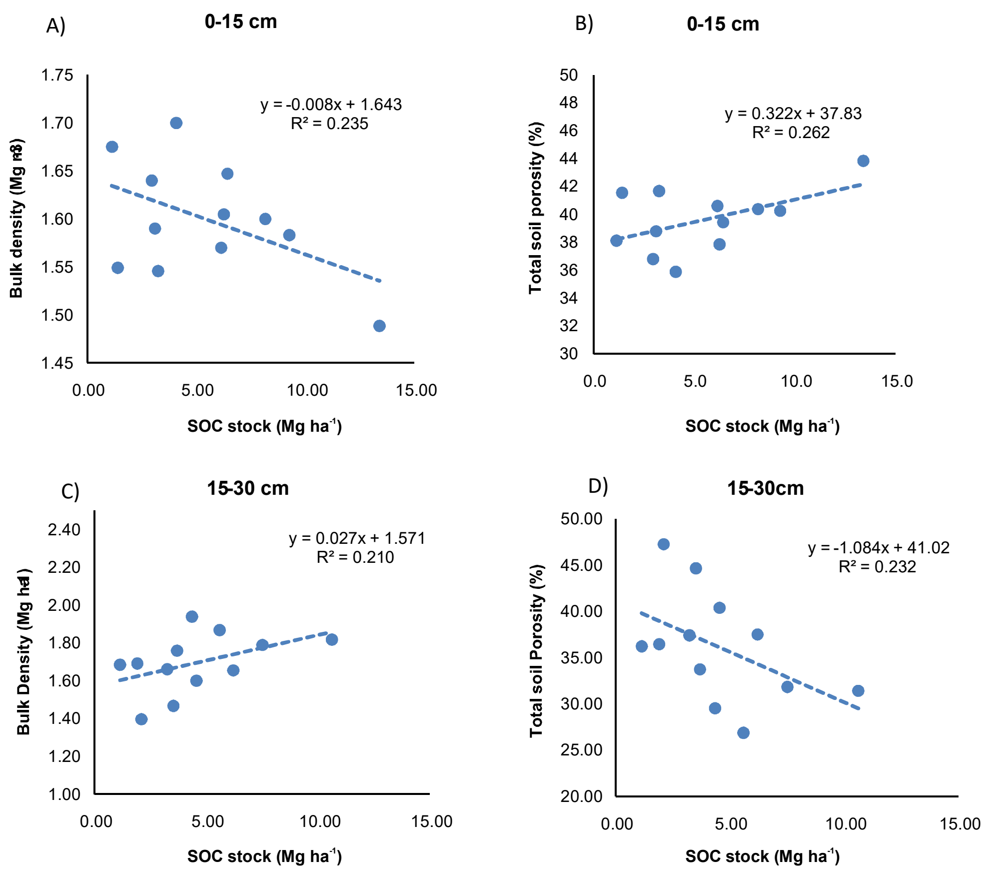

Fig. 1. Relationship of SOC stock (Mg ha^{-1}) with bulk density and total soil porosity in surface (A and B) and sub-surface(C and D) soil in south-western district of Punjab

Table 3. Quantifying the relationship between soil organic carbon (SOC) stock in both surface and sub-surface soils with the physico-chemical properties of soil in South western district of Punjab

SOC	BD	Total porosity	Zn	Fe	Cu	Mn	S
0-15	-0.513*	0.345*	0.112	0.939**	0.580*	0.077	0.169
15-30	-0.649	0.549	0.163	0.551	0.199	0.154	0.214

*and **Correlation is significant at the p<0.05 and p<0.01

years (Table 3). In surface soil the SOC stock explained 26% and in subsurface soil 23% variation in total soil porosity. Whalen et al (2003) explained decrease in bulk density with increasing SOC content could be related to the increase in soil porosity and soil aggregate stability. The relationship of SOC stock withsulphur, Zn, Mn except Fe and Cu was significant but with low correlation coefficient. The low correlation for, Zn and Mn might be related to the formation of strong bond of the former with OM which might have affected the availability of Zn and Mn. The significant strong correlation of 0.939 between SOC stock and Fe might have resulted from reduced condition in paddy and high microbial activity owing to high organic matter (OM) availability in soil (Dhaliwal et al 2019).The increase in available Cu in surface and subsurface soil with increasing SOC stock could be explained from the fact that Cu has greater affinity to form strong inner sphere complex with SOM (Boudesocque et al 2007) and adsorption of Cu^{2+} ions on OM influence the bioavailability of Cu (Matijevic et al.2014).

CONCLUSION

The conversion of sand dunes into cultivable arable land significantly improved SOC stock and physico-chemical properties of the soil except the Mn content, a major micronutrient in rice-wheat cropping systemin both surface and subsurface soil. The formation of hard pan due to puddling in rice resulted in high bulk density in subsurface soil. The wide variation in crop and nutrient management practices had resulted in high coefficient of variation >35% for SOC stock, sulphur and cationic micronutrients. SOC stock was negatively correlated with bulk density in both soil depths and positively correlated with S and cationic micronutrients. Thus, there is need to further study the soil inorganic carbon dynamics, change in microbial flora, a major soil quality indicator to get the realistic and more relevant information on the effect of continuous cultivation of rice-wheat cropping system on the total soil organic carbon stock and soil health.

AUTHOR'S CONTRIBUTION

Harinder Singh designed, supervised and recorded the data of the experiment. Gagandeep Dhawan wrote the original draft of manuscript, reviewed and edited the manuscript. Mandeep Singh analysed and investigated the data and also helped in writing the manuscript. All authors read and approved the final manuscript

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Economic and Environmental Efficacy of Sustainable and Conventional Systems in Paddy-Wheat Cropping System: Insights from Farmer FIRST Project in Punjab

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***Abstract*:** Under Farmer FIRST Project, sustainable technologies including the adoption of short-duration varieties (SDV) of paddy and in-situ residue management techniques like happy seeder were introduced in adopted villages of Punjab. A total of 1500 Frontline Demonstrations conducted across the adopted villages. Sustainable practices consistently resulted in lower costs of cultivation compared to conventional methods ranging from Rs. 3241 to Rs. 6425 per ha resulted in comparable net returns. Furthermore, these practices reduced water usage by 4,190 thousand litres per hectare and mitigated significant amount of atmospheric pollution. The findings of the study revealed the potential of sustainable agricultural practices to enhance both economic profitability and environmental sustainability in paddy-wheat system in Punjab.

Keywords: In-situ management, Short duration varieties, Residue burning

The policy design revolving around food security of the country in the 1960s encouraged a “green revolution” through subsidized input use and high procurement prices. Punjab became the food basket of the country with an increasing area under paddy and wheat by such subsidization. The modern agricultural practices of high yield varieties (HYV) technology in Punjab also simultaneously ushered in the shift from canal irrigation to tube well irrigation as it was a more reliable and flexible source of irrigation (Kaul and Sekhon 1991). Apart from deteriorating soil and water quality, major concern came up for the farming community of Punjab and Haryana is utilization of huge rice residue due to unavailability of economically viable options. Paddy is cultivated on 43.8 Mha in India, producing 118.43 Mt grain and an estimated 165.8 Mt straw (Kaur et al 2022). Every Megagram (Mg) of rice grain harvested produces around 1.4 Mg straw (Satpathy and Pradhan 2020). Due to various socio-economical, institutional, technological and commercial glitches farmers are compelled to burn the residue which leads to onset of an array of problems for the ecosystem. In the year 2023, 36663 farm fire events were recorded in the *kharif* season (PRSC 2023). Similarly, water table of the state is declining day by day. The total annual groundwater recharge of Punjab has been assessed at 18.84 bcm, while annual groundwater extraction stands at 27.8 bcm, resulting in a stage of groundwater extraction of 163.76%. Out of the 150 assessed blocks and 3 urban areas included in the study, 114 blocks and all 3 urban areas (76.47%) have been categorized as 'over-exploited'. Additionally, 3 blocks (1.96%) have been classified as 'critical', and 13 blocks (8.5%) as 'semi-critical' (GOP 2023).

Thus, both the technological shift and the policy directions led to a wide development of natural resources viz soil, water and air necessitated the need of introduction of sustainable systems of paddy-wheat cultivation (Chauhan et al 2012, Bhatt et al 2016). Researcher and policy makers are consistently putting efforts in this direction, resulting in the introduction of technologies which could contribute to the cultivation of these crops in sustainable way. One of the technologies are introduction of short duration varieties of paddy. As long duration varieties of paddy such as Pusa 44 consumes huge amount of water, nutrients and human resources, alternatively short duration varieties of paddy such as PR 121, PR 126 can be grown with less resources (Singh et al 2022a). Similarly, techniques were developed by the researchers to curb paddy residue burning, involving in-situ management of paddy residue through various technologies such as happy seeder, super seeder, smart seeder with the help of these technologies, wheat can be sown in the standing stubbles (Singh et al 2022b).

Thus, blend of short duration varieties of paddy and in-situ management of paddy stubble is a sustainable way to grow paddy and wheat. Further to transfer various sustainable technologies to farmers fields' and popularize among them, Farmer FIRST Programme (FFP) was started by ICAR, and under this programme two villages in Sangrur District of Punjab were adopted by the PAU, Ludhiana in the year 2016-17. To convince the farmers through the grass root level methodology, Frontline Demonstrations (FLDs) short duration varieties of paddy and in-situ management of paddy stubble were conducted in the adopted villages. So, this study was conducted to evaluate the performance of sustainable (SDV+ in-situ management) and conventional approach (LDV + normal sowing of wheat) to generate the research feedback and for policy interventions.

MATERIAL AND METHODS

Farmer FIRST Programme was implemented in Punjab in 2016-17 and two villages from district Sangrur were selected under this programme. To sensitize the farmers regarding water saving and popularization of recommended short duration varieties, 300 Front Line Demonstrations (FLDs) having an area of 0.4 ha for each demonstration of PAU recommended short duration varieties (PR 121 & PR 126) were conducted on farmers' fields in each year from 2017-18 to 2022-23 thus totaling 1500 FLDs in last five years (Table 1). Similarly, demonstrations of in-situ management of paddy residue through Happy Seeder/Super Seeder/Smart Seeder were conducted in the years from 2017-18 to 2022-23.

RESULTS AND DISCUSSION

The yield of SDV paddy remained relatively stable across the years, ranging from 76.38 q/ha in 2022-23 to a peak of 80.65 q/ha in 2017-18 (Table 1). In contrast, LDV paddy generally produced higher yields, particularly in the 2017-18 and 2020-21 seasons with yields of 82.28 q/ha and 82.35 q/ha, respectively. However, decline in LDV yield was observed in 2022-23, dropping to 68.90 q/ha, which is significantly lower compared to the SDV yield of the same year.For wheat, the yields under the in-situ management techniques generally showed an improvement over normal sowing methods. The highest yield for in-situ management techniques was in 2019-20 at 56.85 q/ha, compared to 54.90 q/ha for normal sowing. However, a decline in yield was noted for both methods in 2020-21 and 2021-22, with in-situ management techniques yielding 42.50 q/ha and normal sowing yielding 38.70 q/ha in 2021-22. Despite this decline, in-situ management techniques consistently outperformed normal sowing across the years, indicating its potential benefit in sustainable wheat production.

Economic impact: Sustainable practices consistently resulted in lower costs of cultivation compared to conventional methods in 2017-18, the cost of cultivation for the sustainable approach was Rs. 53,985/ha, compared to Rs. 57,226/ha for the conventional approach, resulting in a savings of Rs. 3,241/ha. This trend continued across the years, with the highest cost savings observed in 2020-21. Gross returns from sustainable practices were slightly lower or comparable to conventional methods in most years, in 2018-19, gross returns were Rs. 238,829/ha for sustainable methods and Rs. 241,681/ha for conventional methods. In 2022-23, net returns for sustainable practices were significantly higher at Rs. 188,038/ha compared to Rs. 168,913/ha for conventional methods. The B.C ratio, which measures the profitability of the cropping system, was consistently higher for sustainable practices and was 5.56 in compared to 5.21 in for conventional methods. This advantage was maintained over the years, with the largest difference observed in 2022-23 (4.51 for sustainable versus 3.93 for conventional).

Environmental impact: Paddy cultivation Sustainable practices i.e. cultivating SDV required fewer irrigations, with an average of 25 irrigations per year compared to 31 for conventional methods. This led to a substantial reduction in both total water use and water footprints per kilogram of yield (Table 3). The in-situ management of paddy stubble using methods viz. Happy Seeder/Super Seeder has proven to significantly reduce the emission of pollutants. The straw load from both short-duration varieties (SDV) and long-duration varieties (LDV) was measured, with SDV showing a lower straw load, which led to a reduced probability of emissions (Table 4). In the demonstration plot with SDV cultivation, considerable reductions in both particulate and gaseous emissions were observed when compared to the check plot with LDV. These findings highlight the potential for lower levels of harmful pollutants being released into the atmosphere through the use of sustainable practices. Over

Table 1. Demonstrations conducted

Year	SDV	In-situ management
2017-18	300	200
2018-19	300	200
2019-20	300	200
2020-21	300	300
2021-22	300	100
2022-23	300	100

Table 2. Impact on paddy yield

Year	Yield (q/ha)			
	SDV	LDV	HST	Normal sowing of wheat
2017-18	80.65	82.28	52.00	51.00
2018-19	78.65	80.41	56.25	55.00
2019-20	79.75	78.40	56.85	54.90
2020-21	78.15	82.35	49.50	49.00
2021-22	79.50	81.20	42.50	38.70
2022-23	76.38	68.90	55.47	53.28

Table 3. Economic analysis of sustainable and conventional paddy-wheat cropping system

Particular	Sustainable	Conventional	Change
2017-18			
Cost of cultivation (Rs/ha)	53985	57226	-3241
Gross returns (Rs/ha)	204905	207268	-2363
Net returns (Rs/ha)	150919	150041	877
B.C ratio	5.56	5.21	0.35
2018-19			
Cost of cultivation (Rs/ha)	62667	66346	-3679
Gross returns (Rs/ha)	238829	241681	-2852
Net returns (Rs/ha)	176161.5	175335	826
B.C ratio	5.60	5.30	0.30
2019-20			
Cost of cultivation (Rs/ha)	64619	67928	-3309
Gross returns (Rs/ha)	242590	239976	2613
Net returns (Rs/ha)	177971	172048	5922
B.C ratio	5.49	5.11	0.38
2020-21			
Cost of cultivation (Rs/ha)	71110	76407	-5297
Gross returns (Rs/ha)	242759	250604	-7845
Net returns (Rs/ha)	171649	174197	-2548
B.C ratio	5.27	5.02	0.25
2021-22			
Cost of cultivation (Rs/ha)	74450	80875	-6425
Gross returns (Rs/ha)	232211	235509	-3298
Net returns (Rs/ha)	157761	154634	3127
B.C ratio	4.19	3.68	0.51
2022-23			
Cost of cultivation (Rs/ha)	82690	86565	-3875
Gross returns (Rs/ha)	270728	255478	15250
Net returns (Rs/ha)	188038	168913	19125
B.C ratio	4.51	3.93	0.58

Cost of cultivation varied from 53985 to 82690. Explain the reasons which facor responsible cots of input or labour

Table 4. Saving in water

Particular	Sustainable	Conventional	Diff
Irrigations (No)	25	31	-6
Total water use (000 litre/ha)	18685	22875	-4190
Water footprints (Litres/kg)	2459	3319	-860

the study period, these reductions translate into substantial avoided atmospheric pollution, contributing positively to environmental sustainability. With the continuous efforts, about 60 percent area was brought under the in-situ paddy residue management technologies. It is estimated that 6 thousand tonne straw burning per annum has been avoided resulted into the avoidance of large amount of pollutants avoidance in the project area. Previous studies also reported the similar findings (Singh *et al* 2022).

CONCLUSION

The implementation of the Farmer FIRST Programme in Punjab has demonstrated the effectiveness of sustainable agricultural practices, specifically the cultivation of short-duration varieties (SDV) of paddy and the in-situ management of paddy residue using techniques. SDV paddy yields remained relatively stable and competitive with long-duration varieties (LDV), while also offering significant benefits in terms of economic and environmental

Table 5. Impact on aatmospheric pollution

Pollutants		Emission factor for rice straw (g/kg dry mass of residue)	SDV (kg/ha)	LDV (kg/ha)	Probable pollution reduction (kg/ha)	Total avoided atmospheric pollution (ton)
Particulate emission	PM	9.64	75.67	98.04	-22.36	58.57
	PM_{10}	6.3	49.46	64.07	-14.62	38.28
	PM_{25}	5.75	45.14	58.48	-13.34	34.94
	BC	0.64	5.02	6.51	-1.48	3.89
	OC	2.2	17.27	22.37	-5.1	13.37
Gaseous emission	CO_2	1220.32	9579.51	12410.65	-2831.14	7414.54
	CO	101.29	795.13	1030.12	-234.99	615.43
	CH_4	9.6	75.36	97.63	-22.27	58.33
	VOC	7	54.95	71.19	-16.24	42.53
	NH_3	4.1	32.19	41.7	-9.51	24.91
	NO_x	1.95	15.31	19.83	-4.52	11.85
	SO_2	0.29	2.28	2.95	-0.67	1.76

Emission factors are calculated from the average of Andreae and Merlet (2001) and Zhang et al (2008) as given in Shrestha et al (2012) in the Emission Inventory Manual

sustainability. Despite occasional fluctuations, SDV consistently produced yields that were less variable than LDV, highlighting its reliability under varying conditions. Economically, the sustainable practices consistently resulted in lower costs of cultivation, higher net returns, and a more favourable benefit-cost (B.C) ratio compared to conventional methods. This economic advantage underscores the viability of adopting sustainable practices for long-term profitability. Environmentally, the sustainable practices significantly reduced water usage and pollutant emissions. The use of SDV and in-situ residue management led to fewer irrigations and a substantial reduction in total water use, thereby lowering the water footprint per kilogram of yield. Additionally, the adoption of in-situ residue management techniques reduced the emission of harmful pollutants, contributing positively to air quality and overall environmental health. In summary, the Farmer FIRST Programme has successfully demonstrated that sustainable agricultural practices not only maintain competitive yields but also enhance economic returns and mitigate environmental impacts.

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AUTHOR'S CONTRIBUTION

Kuldeep Singh: Conceptualization, Methodology, Investigation, Resources, Funding acquisition. Pankaj Kumar: Conceptualization, Methodology, Investigation, Resources, Writing, Funding acquisition. Vajinder Pal: Conceptualization, Methodology, Investigation, Resources, Writing, Funding acquisition. Dalbeer Singh:Writing, Data analysis, Editing.

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Agricultural Vulnerability to Climate Change in Punjab: A Spatio-temporal Analysis

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***Abstract*:** Changing climate and its variability at the regional scale has become a constraint to development in general and poverty reduction specific for low-income countries. The mapping of climatic vulnerability provides a wider approach to understanding its dynamics across space and over time. The study analysed the vulnerability index of 22 districts of Punjab state at four different points of time i.e., 1990, 2000, 2010, and 2020. The uneven weight approach of Iyengar and Sudershan is used to calculate the vulnerability index, which is the sum of exposure and sensitivity minus adaptive capacity. The indicator-wise analysis of vulnerability in Punjab from 1990 to 2020 reveals significant regional disparities. Majha improved its resilience, reducing exposure from 0.47 to 0.19, while Doaba's vulnerability sharply increased from 0.19 to 0.86. Malwa's exposure moderately rose from 0.29 to 0.40, and overall sensitivity slightly declined, yet both Doaba and Malwa became more susceptible to climate risks. The findings emphasize the need for targeted interventions to address rising vulnerabilities, especially in districts like Barnala and Bathinda, which have seen sharp increases in their vulnerability indices.

***Keywords*:** Climatic vulnerability, Vulnerability index, Adaptive capacity, Climate-resilient technologies

Anthropogenic greenhouse gas emissions, driven by economic and population growth, are causing global temperature increases and altering the Earth's climate (Edmonds, Lovell, and Lovell 2020). This shift is significantly impacting both biological and human systems in various regions. Climate change is manifested through rising global air temperatures, extreme weather events, and changes in sea levels, including coastal flooding and the melting of snow and ice (Thornton et al 2014). The impacts are not uniform, as regions like India, with its unique geophysical and hydro-climatic conditions, experience heightened vulnerability to these changes (Gulati et al 2009). India's agricultural sector, which relies heavily on natural resources, faces mounting challenges as global warming exacerbates water scarcity and land degradation. These effects are more pronounced in developing countries, where agriculture plays a significant role in GDP and employment, and where adaptive capacity is often limited. As climate change continues to affect agroecological conditions, the vulnerability of rural populations, who rely heavily on rain-fed agriculture, increases. Climate-induced droughts further exacerbate food insecurity and water shortages (Lyimo and Kanglawe 2010).

The concept of vulnerability to climate change, as outlined by the Intergovernmental Panel on Climate Change (IPCC), includes three key elements: exposure, sensitivity, and adaptive capacity (Füssel and Klein 2006). These factors vary based on biophysical and socioeconomic conditions, which determine how communities respond to climate risks. The vulnerability of systems, particularly in agriculture, is shaped by both internal factors like resource scarcity and external threats such as climate-induced shocks (Hiremath and Shiyani 2013). In India, Punjab is a key agricultural region with a tropical and semi-arid climate. The state has experienced increasing climate variability in recent years, adversely affecting agricultural productivity, groundwater levels, and energy usage, all of which are critical for food security and livelihoods. Given the importance of Punjab's agricultural output to the nation's food supply, it is crucial to understand how climate change is influencing the vulnerability of its districts. Therefore, this study seeks to analyze the vulnerability of different districts in Punjab over time, providing a comprehensive district-level assessment of the agricultural challenges posed by climate change.

MATERIAL AND METHODS

The study encompasses all districts of Punjab, India, except Malerkotla, and focuses on the state's predominantly agrarian economy, which is sustained by an advanced irrigation infrastructure. Nearly 99.6 per cent of the gross sown area and 99.9 per cent of the net sown area are irrigated, with 75 per cent of the irrigation depending on groundwater, a resource that is depleting at an alarming rate (GoP 2021). Punjab's climate exhibits considerable spatial variability, with the Himalayan foothills receiving substantial rainfall, while the southern and western regions experience arid conditions with limited precipitation. Temperature extremes are notable, with May and June being the hottest months (over 40°C), while December to February is the coldest, with average temperatures dropping below 5°C. For this study, secondary data encompassing climatic parameters, crop area, and yield were obtained from Punjab's Statistical Abstracts. Missing data were addressed using interpolation and extrapolation methods. The temporal analysis covers the years 1990, 2000, 2010, and 2020, providing a comparative framework across these time intervals.

Conceptual framework: Assessing vulnerability of a phenomenon requires a solid conceptual framework. The most prevalent method for assessing climate change vulnerability is based on the Intergovernmental Panel on Climate Change (IPCC)'s suggested definition. This approach emphasizes three main components: exposure, sensitivity and adaptive capacity.

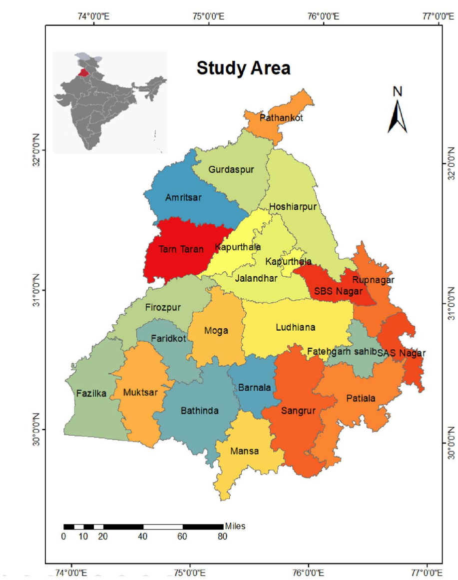

Fig. 1. Study area

Exposure: As indications of exposure, historical changes in climate variables and the occurrence of extreme climatic events are considered, including the rate of change in annual mean maximum temperature, annual mean minimum temperature, and yearly mean precipitation (Table 1). It is expected that as the rate of change of climate variables increased, higher will be the exposure of the households to climate change.

Sensitivity: Degree to which a system is affected or improved either by internal disturbances or external disturbances or both is sensitivity (Gallopin 2003). In this study, the major indicators of sensitivity are percent rural population, crop diversification index, cropping intensity and percentage of marginal and small farmers, percent area under paddy and irrigated land (Table 2).

Adaptive capacity: Adaptive capacity is the third indicator of vulnerability index. It is the ability or potential of a system to adjust to climate variability and extremes, and to cope with its consequences. The major indicators of adaptive capacity are literacy rate, farm holding size, area under food crops, main workers and marginal workers (Table 3).

Iyengar and Sudershan's unequal weight method is used

Table 1. Indicators for exposure

Indicators	Description of the indicator	Unit	Hypothesized relation
Change in Climate variables (from selected base year)	Change in maximum and minimum temperature	Coefficient of trend	+ve
	Change in rainfall	Coefficient of trend	+ve

Table 2. Indicators for sensitivity

Indicators	Description of the indicator	Unit	Hypothesized relation
Percent Rural population	Rural population/Total population × 100	Per cent	+ve
Crop diversification Index	Simpson index	Unit less	-ve
Cropping intensity	Gross cropped area under agriculture with reference to net cropped area under agriculture	Per cent	-ve
Percentage of marginal and small farmers	Percentage	Per cent	+ve
Percent area under paddy	Paddy area/net area sown × 100	Per cent	+ve

Table 3. Indicators for adaptive capacity

Indicators	Description of the indicator	Unit	Hypothesized relation
Literacy rate	Proportion of persons aged 15 years or older who are able to read and write	Per cent	+ve
Farm holding size	Average farm size	Hectare	+ve
Area under food crops	How much area under food crops	Thousand hectare	+ve
Main workers	Number of total main worker	Number	+ve
Marginal workers	Number of marginal workers	Number	+ve

to work out a composite index from multivariate data. The determination of the weights in this manner would ensure that large variation in any one of the indicators would not unduly dominate the contribution of the rest of the indicators and also distort inter-regional comparisons. The vulnerability index is the sum of exposure and sensitivity minus adaptive capacity. A lower index value implies low vulnerability, whereas a larger value indicates high vulnerability. The districts are classified into three categories; low, medium, and high using the Jenks optimization method in ArcGIS 10.2.2 software. It is one of the methods of data clustering into different classes (Chaudhary and Sirohi 2022).

RESULTS AND DISCUSSION

The classification of districts based on vulnerability using a single index value facilitates the identification of shifts in vulnerability status across the districts of Punjab state. The study also presents below the descriptive statistics for the variables assessed regarding exposure, sensitivity, and adaptive capacity at the state level.

Descriptive statistics: The mean value of exposure during 1990 and 2020 was observed at 0.43 and 0.48, respectively showing an increase of 11.63 per cent in the last four decades. The trend of maximum temperature is more or less the same, but minimum temperature and rainfall declined over time attributed to the increased exposure of agriculture.

In case of sensitivity, the mean value was 0.18 during 1990 and 0.83 during 2020 which increased about five times during the study period. The percent rural population is declining in Punjab over time due to urbanization and migration. During 1990 to 2020, Simpson crop diversification index declines from 0.65 in 1990 to 0.41 in 2020 due to adoption popular wheat-paddy crop rotation which provided assured income to the farmers. Changing tenancy structure of the state (Sharma 2010) due to increase in the lease-in land over time (Sachdeva et al 2017), resulted in the decline in the proportion of marginal and small farmers in the state over time. Significant increase in the per cent paddy area to net area sown was found to be the major factor responsible for increasing the sensitivity in the Punjab state (Ali et al 2017).

The mean value for adaptive capacity was recorded 0.09 during 1990 and 0.49 during 2020 showing five times increase in last 40 years. The mean value of the vulnerability index was found 0.52 in the year 1990 and 0.82 for the year 2020 which showed an increase of 57.69 per cent. Increased average literacy rate, number of marginal workers and average farm size holdings were the major factors contributing to the increase in adaptive capacity of across the districts of the Punjab state. The decline in main workers and non-workers along with decrease in area under food crops has decreased the adaptive capacity.

Indicator-wise analysis of vulnerability index

Exposure assessment: Exposure refers to the presence of people, ecosystems, and assets that are vulnerable to negative impacts in specific areas, as defined by the IPCC (2014). In the context of the table provided, the regions of Punjab (Majha, Doaba, and Malwa) display different exposure levels for the years 1990 and 2020, reflecting changes over time due to climatic variations. In 1990, Majha had a relatively high exposure index of 0.47, indicating significant vulnerability, but by 2020, this index decreased to 0.19, suggesting reduced exposure. This reduction could be attributed to less variation in climatic factors in this region, similar to how some districts moved from high to low exposure. Conversely, the Doaba region saw an increase in exposure from 0.19 in 1990 to 0.86 in 2020, reflecting greater susceptibility over time, possibly due to higher variability in climate patterns, such as temperature and rainfall trends.For the Malwa region, there was a moderate shift from 0.29 in 1990 to 0.4 in 2020, signifying an increase in exposure, though not as drastic as in Doaba region.

Overall, the combined index for Punjab shows an increase from 0.37 in 1990 to 0.61 in 2020, suggesting that the state as a whole became more exposed to potential risks, primarily due to fluctuating climate variables like temperature and rainfall, paralleling the observed shifts in district-level exposure.

Sensitivity assessment: The degree to which a system is affected, either adversely or beneficially, by climate-related stimuli. The effect may be direct (e.g., increase in area under paddy due to assured irrigation through power subsidy) or indirect (e.g., decrease in crop diversification due to assessed grain market in the state) (Fig. 3). The sensitivity index measures how susceptible a region is to adverse impacts when exposed to risks, such as climate variability. The sensitivity of different regions in Punjab-Majha, Doaba, and Malwa-over the years 1990 and 2020 is compared. In Majha, the sensitivity index decreased from 0.57 in 1990 to 0.38 in 2020, indicating that this region became less vulnerable over time. This could be due to adaptive measures or a decrease in the factors that heighten vulnerability, such as dependency on sensitive ecosystems or agriculture practices that were more prone to climate change impacts in the past. Doaba, on the other hand, experienced a substantial increase in sensitivity, from 0.35 in 1990 to 0.92 in 2020. This sharp rise suggests that the region became more vulnerable to adverse effects, possibly due to changes in agricultural patterns, water availability, or socio-economic factors, making it more susceptible to environmental stressors. For Malwa, the sensitivity index also increased significantly, from 0.08 in 1990 to 0.59 in 2020, reflecting growing vulnerability in this region. The increase indicates that previously, Malwa had a relatively low sensitivity to environmental changes, but over time, it has become more sensitive, likely due to shifts in land use, resource depletion, or socio-economic pressures.

Overall, the combined sensitivity index for Punjab decreased slightly from 0.83 in 1990 to 0.72 in 2020. While some regions like Majha showed improved resilience, the overall sensitivity remains high, largely due to the significant increases in Doaba and Malwa. This reflects a complex interplay of environmental and socio-economic factors, where certain areas have become more adaptable, while others have seen their vulnerability increase

Adaptive capacity: The adaptive capacity index measures the ability of a region to adjust to, mitigate, or recover from adverse impacts, such as those caused by climate change (Table 5, Fig. 4). In Majha, the adaptive capacity index increased from 0.38 in 1990 to 0.6 in 2020, indicating that the region has improved its ability to cope with and adapt to changing conditions. This could be due to better infrastructure, technology adoption, or improved socio-economic conditions that enhance resilience against environmental challenges. Doaba saw a dramatic improvement in adaptive capacity, with the index rising from 0.13 in 1990 to 0.79 in 2020. This suggests significant advancements in the region's ability to manage and mitigate the effects of climate change, likely through improved agricultural practices, access to resources, and development initiatives aimed at increasing resilience. In Malwa, the adaptive capacity also increased, though less drastically, from 0.04 in 1990 to 0.48 in 2020. While this is a notable improvement, it shows that Malwa had very low adaptive capacity in 1990, and despite the progress, it remains

Table 5. Indicator-wise analysis of vulnerability index

Indices	1990	2020
Exposure (Index)		
Majha	0.47	0.19
Doaba	0.19	0.86
Malwa	0.29	0.40
Overall Index	0.37	0.61
Sensitivity Index	1990	2020
Majha	0.57	0.38
Doaba	0.35	0.92
Malwa	0.08	0.59
Overall Index	0.83	0.72
Adaptive capacity (Index)	1990	2020
Majha	0.38	0.60
Doaba	0.13	0.79
Malwa	0.04	0.48
Overall Index	0.47	0.88

Table 4. Descriptive statistics of selected variables (Mean ± SD)

Variables	1990	2000	2010	2020
Exposure	0.43 ± 0.23	0.45 ± 0.21	0.39 ± 0.23	0.48 ± 0.26
Minimum temperature (Coefficient of trend)	0.06 ± 0.001	0.06 ± 0.01	0.07 ± 0.01	-0.03 ± 0.01
Maximum temperature (Coefficient of trend)	0.04 ± 0.01	0.04 ± 0.01	-0.02 ± 0.02	0.03 ± 0.01
Rainfall (Coefficient of trend)	27.13 ± 20.08	-11.41 ± 11.62	16.06 ± 12.70	-26.71 ± 18.5
Sensitivity	0.18 ± 0.18	0.58 ± 0.32	0.61 ± 0.29	0.83 ± 0.19
Rural population (%)	71.9 ± 8.79	68.96 ± 11.46	66.15 ± 13.02	66.65 ± 12.7
Crop diversification index	0.65 ± 0.19	0.68 ± 0.05	0.65 ± 0.05	0.41 ± 0.19
Cropping intensity (%)	163.56 ± 24.49	182.89 ± 11.69	188.56 ± 11.51	190.48 ± 8.24
Marginal and small farmers (%)	46.21 ± 10.09	29.97 ± 13.30	33.94 ± 13.58	34.70 ± 12.13
Area under paddy (%)	5.81 ± 3.94	32.27 ± 8.83	18.05 ± 6.21	73.60 ± 18.46
Adaptive capacity	0.09 ± 0.14	0.39 ± 0.18	0.56 ± 0.18	0.49 ± 0.21
Literacy rate (%)	40.55 ± 7.95	68.79 ± 8.56	74.32 ± 7.11	74.79 ± 7.13
Main worker (number)	508198 ± 341217	455043 ± 255951	385596 ± 257789	363597 ± 246608
Marginal worker (number)	10478 ± 9022	75981 ± 42914	68921 ± 34709	65747 ± 33795
Non-worker (number)	1006858 ± 443334	895975± 532088	859995± 489541	811181 ± 471823
Area under food crops (000' ha)	479 ± 171	385 ± 201	345 ± 156	321 ± 138
Farm size holdings (ha)	3.61 ± 0.97	4.36 ± 1.20	3.81 ± 1.34	4.18 ± 2.05

somewhat less adaptive compared to other regions. This could indicate that while efforts have been made to enhance resilience, challenges such as resource limitations or socio-economic constraints persist.

The overall adaptive capacity index for Punjab rose significantly from 0.47 in 1990 to 0.88 in 2020. This overall increase suggests that, as a state, Punjab has greatly improved its capacity to adapt to environmental and climatic challenges. The rise in adaptive capacity indicates better preparedness, likely through improved infrastructure, agricultural techniques, and policy interventions aimed at sustainability. This enhanced adaptive capacity positions the state to better withstand future environmental and socio-economic pressures.

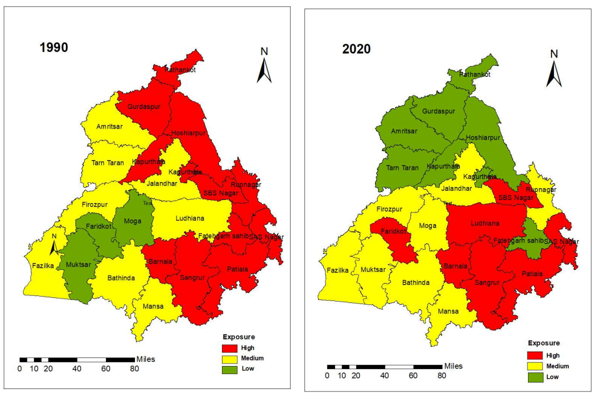

Fig. 2. Exposure composite index among districts of Punjab, 1990 and 2020

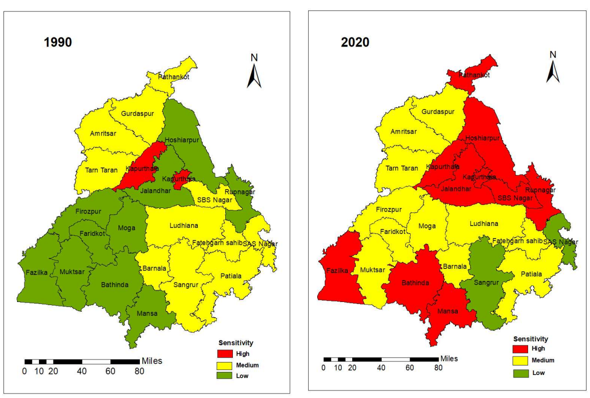

Fig. 3. Sensitivity composite index among districts of Punjab, 1990 and 2020

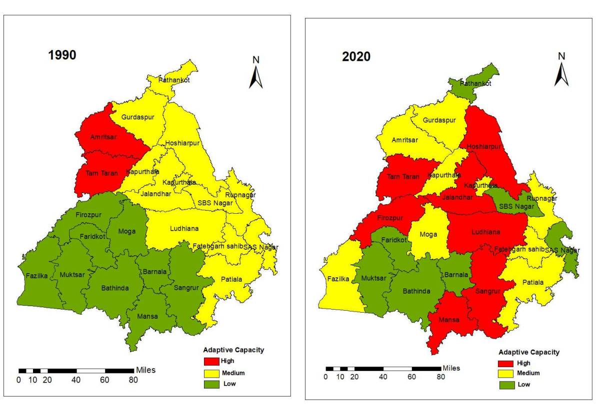

Fig. 4. Adaptive capacity composite index among districts of Punjab, 1990 and 2020

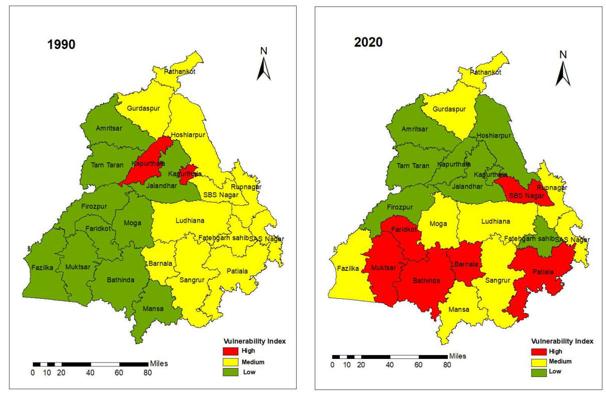

Fig. 5. Vulnerability composite index among districts if Punjab, 1990 and 2020

Table 6. District-wise comparison of vulnerability index between 1990 and 2020

District	1990	2020
Amritsar	0.45	0.5
Barnala	0.00	1.00
Bathinda	0.52	1.00
Faridkot	0.10	1.00
Fatehgarh Sahib	0.52	0.53
Fazilka	0.52	0.75
Firozpur	0.52	0.55
Gurdaspur	0.74	0.68
Hoshiarpur	0.16	0.48
Jalandhar	0.65	0.27
Kapurthala	0.00	0.61
Ludhiana	0.55	0.91
Mansa	0.52	0.77
Moga	0.10	0.75
Sri Muktsar Sahib	0.10	1.00
Pathankot	0.74	0.91
Patiala	0.52	1.00
Rupnagar	0.23	0.97
Sangrur	0.00	0.96
SAS Nagar	0.52	0.67
SBS Nagar	0.52	1.00
Tarn Taran	0.45	0.34

District-wise analysis of vulnerability index: Vulnerability is the propensity or predisposition to be adversely affected (Table 6). Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.

The vulnerability analysis across the districts in Punjab between 1990 and 2020 reveals significant shifts in exposure to environmental risks. Several districts, such as Barnala, Bathinda, Faridkot, Sri Muktsar Sahib, Patiala, SBS Nagar, and Sangrur, which were categorized as low or moderately vulnerable in 1990, saw a sharp increase in their vulnerability index, reaching close to or at 1.00 by 2020. This shift highlights the increasing susceptibility of these regions to climatic and environmental changes over time. The rise in vulnerability in districts like Rupnagar and Ludhiana further emphasizes the growing concerns related to resource degradation and climate variability. In contrast, districts like Jalandhar and Tarn Taran exhibited a decline in vulnerability, shifting from moderate levels in 1990 (0.65 and 0.45, respectively) to low levels in 2020 (0.27 and 0.34). This reduction in vulnerability indicates some improvement in resilience and adaptive capacity within these regions. Hoshiarpur, Kapurthala, and Gurdaspur, which initially had moderate exposure, remained in similar vulnerability classes, showing more stability over the decades. Furthermore, the analysis identifies districts like Fazilka, Moga, and Mansa as regions that shifted from low to moderate vulnerability. These districts, along with others that have become more exposed, are reflective of the variability in environmental stressors, such as fluctuations in temperature and rainfall patterns, which contribute to rising risks.

Overall, the findings suggest that while some districts have made strides in reducing vulnerability, a significant portion of Punjab has experienced worsening conditions, particularly in the Malwa region. This trend underscores the need for targeted interventions to mitigate environmental risks and enhance adaptive capacities, especially in districts that have transitioned from being relatively safe to highly vulnerable over the past three decades.

CONCLUSIONS

In conclusion, while Punjab's agriculture has been a cornerstone of India's food security since the Green Revolution, significant challenges such as groundwater depletion and paddy stubble burning have emerged over time, necessitating government interventions to enhance adaptive capacity. Despite these efforts, the region remains vulnerable due to decreased agricultural diversification, driven by market assurances for grains and improved irrigation facilities. This study highlights a concerning upward trend in climatic vulnerability, underscoring the urgent need to enhance adaptive capacity alongside reducing sensitivity. Strategies such as promoting crop diversification through cooperatives, implementing a "one district, one product" initiative, and enhancing literacy and labor force participation are essential to mitigate vulnerability. Additionally, fostering the establishment of new farmer producer organizations (FPOs) and NGOs, coupled with training programs and the dissemination of climate-resilient technologies, can significantly bolster the region's capacity to adapt and thrive in the face of climatic challenges.

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Determinants of Vegetable Production among Smallholder Farmers in Diverse Agro-Climatic Zones of Himachal Pradesh

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Abstract: The study was conducted to examine the factors affecting the vegetable production among smallholder farmers in Himachal Pradesh. The primary data collected with structured questionnaire and analyzed by using descriptive and multiple regression analysis. Multiple regression analysis showed that the factors like farm size, experience, farm workers and extension services were positive and significant relationship with vegetable production. The coefficient of age (-0.002) showed negative and significant relationship with vegetable production means older age farmers usually use traditional practices on the field due to lack of knowledge about modern inputs and technology. The 74 per cent variation in the model was explained by the independent variables under study while the remaining 26 per cent was due to other variables like sowing time, irrigation facilities, improved and quality seeds etc. Lack of irrigation facility, price fluctuations and lack of transportation facilities were found to be significantly different from different zones as revealed by significant chi-square value 8.38, 7.86 and 11.80. The improving education, access to modern agricultural practices, reducing regional disparities in input and market access could significantly enhance vegetable production in Himachal Pradesh. They suggested that the farmers need to be educated to apply the recommended package of practices in order to avoid increasing the cost of cultivation unnecessarily and decrease the cost of production.

Keywords: Vegetables, Farm size, Market availability, Smallholder farmers

India is second largest producer of vegetables in the world with annual production of 204.63 million tonnes from an area of 11.35 million hectares having productivity of 18.02 tonnes/hectare (NHB, 2023).The production of vegetables increases every year to fulfill the demand, though farmers are unaware about the quantity to produced and supply to the market as they lack understanding about market trends and forecast about future demand. This led to rapid fluctuations of prices in vegetables marketing due to glut or scarcity (Reddy et al 2018). Among all the North-Western states, Himachal Pradesh has the highest rate of growth in fruit and floriculture crops and ranks second in vegetable production (Sharma et al 2003). Shimla, Sirmaur, Solan, Kangra, Mandi and Kullu are the main vegetables producing districts. In Himachal Pradesh, the area under vegetables is 9,199 thousand hectares, with a production of 1,875.24 thousand metric tonnes and a productivity of 20.38 MT/ha (Directorate of Economics and Statistics, 2023). There is a good scope for commercialization of the agriculture sector for enhancing income and generating additional gainful employment opportunities. It is a hilly and mountainous state in India, which is separated by the Shiwalik hills from the monotonous plains of Punjab. It has a unique landmass represented by mountainous ranges, hills and valleys. Moreover, vegetables are highly seasonal, resulting in fluctuations in market arrival and prices. These irregular patterns along with lack of market intelligence increase the despairs of the growers (Kundu et al. 2019). With the above background, this study was conducted to examine the factors affecting vegetable production in Himachal Pradesh.

MATERIAL AND METHODS

Selection of the sample: Stratified multistage random sampling technique was used to select the ultimate respondents i.e. the vegetable growers. The selection of sampled households was done from all the four agro-climatic zones of Himachal Pradesh. At the first stage, two niche areas/ blocks from each agro-climatic zone were selected purposively on the basis of area under vegetable cultivation. At the second stage, a list of gram panchayats from each selected blocks was prepared and out of which 5 were selected from each selected block.At the third stage, a list of vegetable growers of the selected gram panchayat was prepared and out of which 10 farmers from each selected were selected randomly for collection of the primary data. Thus, sample of 400 vegetable growers were selected for the present study (Table 1).

Analytical Tools

Multiple regression analysis: Multiple regression analysis was carried out to examine the different factors affecting the vegetable production of the farmers. The model equation is specified as follows:

Table 1. Selected blocks from each agro-climatic zones of Himachal Pradesh

Zones	No. of selected blocks	No. of selected blocks	Latitude	Longitude
Sub-Montane and Low Hills Sub-Tropical Zone (Zone-I)	2	Una	31°28'48"N	76° 16'48"E
		Nadaun	31°48'12"N	76° 23'0"E
Mid-Hills High Humid Zone (Zone-II)	2	Balh	31°40'24"N	76° 59'0"E
		Kangra	32° 05'36"N	76° 15'48"E
High Hills Temperate Wet Zone (Zone-III)	2	Kullu	31° 57'30"N	77° 06'30"E
		Theog	31° 13'34"N	77° 25'24"E
High Hills Temperate Dry Zone (Zone-IV)	2	Kalpa	31° 32'36"N	78° 14'0"E
		Lahaul	32° 34'24"N	77° 02'0"E

$$Y= a_0 +a_1X_1+a_2X_2+a_3X_3+a_4X_4+a_5X_5+ a_6X_6+ a_7X_7$$

Where,

Y= Gross returns (Rs. /year), a_0=Constant, X_1 = Farm size (Bigha)

X_2=Age of farmer (years), X_3=Education (No. of schooling years)

X_4=Years of experience (No. of years), X_5=Farm workers (No.)

X_6=Extension Services (1 if yes, otherwise 0), X_7=Market availability (1 if yes, otherwise 0)

a_1 to a_7 are the regression coefficients

Garrett's ranking: Garrett's ranking technique was used to analyze these various constraints experienced by the famers in different zones in the study area. The prime advantage of this technique over simple frequency distribution is that the constraints are arranged based on their severity from point of view of the farmers (Zalkuwi et al 2015). The farmers were asked to assign the rank for each category of the constraints proposed by them. The per cent position for each rank was calculated with the help of the following formula.

$$\text{Per cent position} = \frac{100\,(Rij - 0.50)}{Nij}$$

Where,

Rij = Rank given to the i^{th} factor by the j^{th} respondent,

Nij = Number of factor ranked by the j^{th} respondent,

Further, in order to test the significant difference for the problems among different zones, Chi-Square test was used. The quantity χ^2 describes the magnitude of the discrepancy between theory and observation. The detail of approximate Chi-square test (χ^2) is given as under:

$$\chi^2 = \sum_{i=1}^{n} \frac{(0-E)^2}{E} \sim\sim \chi^2(L-1)\text{d.f.}$$

Where, O = Observed values, E =Expected values, L = Number of different zones

RESULTS AND DISCUSSION

Farm size, age, education, experience, family workers, extension services and market availability were major seven variables analyzed. All these variables were significantly influenced the vegetable production in the study area (Table 2). At overall level, the coefficient of farm size (0.13) was positive and significant factor for vegetable production this means that 1 per cent change in farm size, the vegetable production will change by 0.13 per cent Aburr (2014) and Umar and Abdulkadir (2015) also made similar observations. Education showed the positive and significant relationship with vegetable production across all the zones. Educated households were exposed various aspects of production information and able to manage farm production better. The coefficient of experience was positive and statistically significant in all zones. This implies that the farmers having more years of experience, tends to be more efficient in producing vegetables. Adeoye (2020) found that experience gathered over time in the production of the commodity may be put into use to improve practices in the production. The coefficient of age (0.003 and 0.002) was positive and significant relation with vegetable production in Zone-I and Zone-II. The positive value implied that older age farmers were more years of experience in the production of vegetables as compared to the younger farmers. Age is one of the important determinants of agricultural production because age of farmer may affect adoption of agricultural innovations. In case of Zone-IV, the coefficient of age showed negative and significant relationship with vegetable production. At the older age farmers usually use traditional practices on the field due to lack of knowledge about modern inputs and technology.

The extension services and farm workers had positive and significant relationship with vegetable production. If there is 1 per cent increase in extension services and farm workers, the production will increase by 0.05 and 0.03 per cent, respectively. The extension services provide latest information on production techniques. The adjusted R^2 indicates that 74 per cent variation in the model was explained by the independent variables under study while the remaining 26 per cent was due to other variables like sowing

Table 2. Estimates of multiple regression analysis for vegetable production

Variables	Zone-I	Zone-II	Zone-III	Zone-IV	Overall
Constant	4.01	3.12	4.10	4.33	4.35
	(0.15)	(0.16)	(0.14)	(0.07)	(0.05)
Farm size	0.16*	0.10*	0.12*	0.14*	0.13*
	(0.02)	(0.01)	(0.02)	(0.02)	(0.01)
Age	0.003***	0.002***	-0.002	-0.002**	-0.003*
	(0.001)	(0.001)	(0.002)	(0.001)	(0.001)
Education	0.02***	0.01***	0.02**	0.01	0.01*
	(0.02)	(0.01)	(0.01)	(0.02)	(0.001)
Experience	0.01**	0.01**	0.02*	0.02*	0.01*
	(0.01)	(0.00)	(0.00)	(0.01)	0.002)
Farm workers	0.02	0.02***	0.03	0.04***	0.03***
	(0.03)	(0.01)	(0.02)	(0.03)	(0.02)
Extension services	0.03	0.02	0.06***	0.06**	0.05**
	(0.05)	(0.03)	(0.04)	(0.04)	(0.02)
Market availability	0.10***	0.25*	0.21***	0.01	0.07*
	(0.06)	(0.13)	(0.12)	(0.04)	(0.02)
R^2	0.70	0.78	0.72	0.75	0.74

*, **, and *** significant at 1 per cent, 5 per cent &10 per cent level of significance, respectively
Figures in parenthesis are standard error

time, irrigation facilities, improved and quality seeds etc.

Problems Faced by Vegetable Growers

Garret ranking technique: The major constraints were identified first and then farmers' were ask to gave rank to the problems according to superiority of problems between 1 to 17 (Table 3). The fluctuation in prices were 1st ranked problem with the Garret mean score (56.29) followed by high wage rate , high input cost, lack of transportation facilities, unavailability of irrigation facilities, high commission charges and insect /pest disease were the major problems faced by farmers. These constraints highlight the significant challenges faced by vegetable growers; affect their production efficiency, cost-effectiveness, and overall profitability.

Chi-square test: Chi square test shows that a problem faced by farmers was varying between different zones (Table 4). The major production problems faced by farmers were high wage rates (87%), scarcity of skilled labor (83%), high input costs (78%), lack of irrigation facilities (77%), and insect/pest attacks/ diseases etc. (76%). The high wage rate is of significant concern due to the shortage of local labor and increased migration to urban areas for non-agricultural employment, resulting in greater dependence on expensive hired labor. This increased labor cost directly impacts production expenses, reducing profit margins and overall economic viability for farmers. About 90 per cent of farmers in Zone-II reported that the pest and disease problems, indicating widespread crop losses due to limited pest management practices. The lack of irrigation facilities showed a significant different across the zones, with Zone-IV

Table 3. Production and marketing constraints of sampled vegetable farmers

Particulars	Garret mean score	Rank
Fluctuation in prices	56.29	I
High wage rate	54.57	II
High Input cost	52.88	III
Transportation facility not available/costly	52.61	IV
Lack of irrigation facilities	50.94	V
High commission charges	50.59	VI
Insect/pest/ disease attack	50.44	VII
Non-availability of good quality seeds/planting material	50.35	VIII
Scarcity of skilled labour	50.3	IX
Lack of subsidy for inputs	49.69	X
Lack of marketing facilities nearby	49.44	XI
Lack of storage facilities	49.36	XII
Lack of technical Knowledge	48.69	XIII
Wild animals/Monkey menace	46.12	XIV
lack of market information	45.96	XV
lack of packing material	43.76	XVI
Non-availability of chemicals/ pesticides/fertilizers on time	40.17	XVII

Table 4. Zone-wise problems faced by vegetable growers (Multiple response %)

Particulars	Zone-I	Zone-II	Zone-III	Zone-IV	Overall	Chi-Square
Production constraints						
High Input cost	75	70	75	90	78	2.90
Insect/pest/ disease attack	65	90	80	75	76	4.13
Lack of irrigation facilities	55	80	84	87	77	8.38*
High wage rate	75	86	94	94	87	2.78
Lack of technical Knowledge	69	83	71	75	75	1.54
Non-availability of good quality seeds/planting material	60	70	85	80	73	4.71
Scarcity of skilled labour	82	84	70	95	83	3.80
Lack of subsidy for inputs	67	75	70	78	72	1.53
Wild animals/Monkey menace	70	70	82	72	74	1.35
Non-Availability of chemicals/ pesticides/fertilizers on time	55	72	65	82	69	5.68
Marketing constraints						
Transportation facility not available/costly	55	67	70	95	72	11.80*
High commission charges	69	67	90	85	78	5.08
lack of market information	60	70	77	84	73	4.33
lack of packing material	67	65	75	80	72	2.05
Lack of marketing facilities nearby	60	55	50	90	64	15.20*
Lack of storage facilities	70	50	80	70	68	7.04
Fluctuation in prices	67	70	92	96	81	7.86*

* Significant at 5 per cent level

having the highest percentage of affected farmers (87%) and Zone-I having the lowest (55%). This indicates a disparity in infrastructure development, with regions lacking investment in water resource management facing higher production risk. Price fluctuations were also a major issue, affecting 81 per cent of farmers overall, particularly in Zones III and IV. Unpredictable market prices arise due to supply-demand mismatches, poor market linkages, and inadequate government intervention, leading to income instability. The unavailability or high cost of transportation was reported by 72 per cent of farmers, with significant variation across zones. Poor infrastructure and a lack of efficient transport facilities increase logistics costs, reduce profit margins, and limit access to distant markets. This is especially pronounced in Zone-IV, where 95 per cent of farmers reported this issue. The unavailability of marketing facilities, reported by 64 percent of farmers, significantly affected Zone-IV (90%). Without access to nearby markets, farmers were forced to sell their produce at lower prices to local agents, leading to reduced earnings. Various significant problems such as lack of irrigation facilities, transportation facilities and price fluctuations in Zone-IV which means other zone farmers does not faced these problem as much as compare to Zone-IV. Lack of irrigation facility and lack of transportation facilities were found to be significantly different from different zones as revealed by significant Chi-square value (8.38, 11.80). Similar trend was observed in earlier studies(Kumar 2011,Sharma 2019, Barwal et al 2022).

CONCLUSION

Several factors significantly impact the vegetable production in Himachal Pradesh, such as farm size, age, education, experience, number of farm workers, availability of extension services, and market access. Farm size, more years of farming experience, higher levels of education, and access to extension services were positively associated with increased vegetable production. However, vegetable growers faced numerous production marketing constraints such as high input costs, insect/pest attack, scarcity of skilled labor and price fluctuations, lack of transportation facilities, and high commission charges. The study concluded that improving the education, access to modern agricultural practices, and reducing regional disparities in input and market access could significantly enhance vegetable production in Himachal Pradesh. Training on modern methods of production should be provided to the farmers before vegetable sowing and along the guidance of appropriate practices suited to small and marginal farms.

AUTHOR'S CONTRIBUTION

Dr. Subhash Sharma provides as conceptualization, supervision and guidance, Dr. Diksha Bali helped in the selection of sampled vendors for the collection and sorting the data, analysis of data Dr. Chinglembi assisted in interpretation of data and write up of the article.

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Constraints for Adopting Climate Smart Practices in Major Crops amongst Punjab Farmers

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***Abstract*:** Climate change has evolved into a crucial concern with significant social, economic, and environmental implications in the present era. The concept of climate smart agriculture (CSA) has emerged as holistic approach, incorporating climate adaptation, mitigation and sustainable development principles into agricultural systems as a strategy to combat climate change. Despite the documented benefits, the rate at which farmers are adopting these practices remains notably low. The present study aimed to identify the main climate smart practices (CSPs) adopted and constraints faced a sample of 240 farmers for the adoption of CSA in Punjab agriculture. The main seven practices i.e, short duration varieties (SDV), laser land leveling (LLL), direct seeded rice (DSR), zero tillage (ZT), happy seeder (HS), Super seeder (SS) and baling (B) were identified as CSPs in the study area.The major constraints for adoption of climate resilient technologies were more legal paper work, erratic power supply and limited extension activities. The study suggested that more extension services, education programs for farmers, demonstrating and trainings on new CSP are necessary for making farming more resilient economically and ecologically.

***Keywords*:** Climate change, Climate smart agriculture, Adaptation, Constraints

Climate change presents a significant challenge to global agricultural production, giving rise to both direct and indirect consequences (Kaur et al 2018). Changing climate in agriculture sector impacts crops, livestock, forestry, and aquaculture having serious social and economic implications (Esar and Sachdeva 2023, Chandel et al 2022). Consequences can be low incomes, eroded livelihoods, trade disruptions, adverse health impact etc (Chakrabarty 2016, Kumar et al 2023). In reducing the negative impacts of climate change, the most efficient way seems to be adaptation strategies (Surendran et al 2016, Kumar and Kaur 2018, Gangadhar 2020). The UN Food and Agriculture Organization introduced the concept of Climate Smart Agriculture (CSA) for the first time in 2010. CSA has been presented as a strategy to combat climate change while simultaneously tackling the challenges posed by GHG emissions (Managa and Nkobolemhlongo 2016).

CSA holds the promise of enhancing productivity and resilience in a sustainable manner, while simultaneously curbing GHG emissions. This, in turn, contributes to advancing both food security and regional development objectives (FAO 2016). It represents a path for reshaping and revitalizing agricultural progress to adapt to the emerging realities of climate change (Lipper et al 2014). The three fundamental pillars of CSA encompass increased productivity, improved resilience in the face of climate change, and the mitigation of greenhouse gas emissions. Within this framework, agricultural techniques and technologies that align with climate-smart principles can contribute to achieving at least one of these pillars. Despite the profound benefits of these technologies they are securing only a creeping rate of adoption (Aryal et al 2018, Jasna et al 2016). The main critique of CSA concerns its technically oriented nature (Taylor 2018, Autio et al 2021).

Various studies have shown that the farmers' decision of non-adoption or partial adoption could be rational due to the existing conditions that restrain adoption (Rodriguez 2005). Lack of knowledge about cultivation practices, lack of availability of seeds in the market, resistance to change the conventional practices, lack of adequate information on CRA technologies and weather status to plan their farming activities, and high cost for construction of well or farm pond were some of the constraints faced by the farmers (Rohila et al 2018, Mishra and Malik 2024). Constraints hampers the potential to find out, to approach and to handle the risk that decreases the adverse effect related to climatic event and also affects the development and application of adaptation into use. Farmers face number of constraints when adapting to the changing climatic conditions Therefore, to understand the constraints experienced by the farmers while adapting the change in the climate, become important that too for the adversely affected regions (Shelar et al 2022). The present study aims to identify the main CSA practices being adopted and the reasons for their adoption, sources for disseminating information of these practices and the constraints faced by farmers during adoption of CSA practices.

MATERIAL AND METHODS

The study was conducted in the Punjab state of India. For the selection of the sample farmers, multistage sampling technique was used. In the first stage, one district from the Kandi (Roopnagar), three from the central zone (Sangrur, Patiala and Fatehgarh Sahib) and two from the southwestern zone (Mansa and Sri Muktsar Sahib) were selected based on the percentage distribution of the area under zones in Punjab state. Two villages from each district were selected randomly in the second stage. Total 12 villages had been selected (Table 1).

Later at the third stage, a list of farmers engaged in cultivating paddy and wheat crops was prepared. With the consultation of KVK scientists and other extension specialists like agriculture development officers, various climate smart practices applicable to paddy and wheat cultivation i.e, direct seeding of rice, short duration varieties of paddy, laser land leveling, baling, use of super seeder, happy seeder, zero till drill in wheat sowing were identified. Paddy and wheat are the main crops of Punjab which are dominating the state agriculture. From the list of farmers, 20 farmers, were selected from each village, ensuring a combination of both adopters and non-adopters of climate smart practices. In total, the final sample consisted of 240 farm households engaged in the cultivation of either paddy, wheat, or both crops, while also considering their adoption status of climate smart practices.

Garrett Ranking method was used to evaluate the problems faced by farmers for adoption of CSPs (Reddy et al, 2024). The farmers were asked to rank the given problem according to the magnitude of the problem. The orders of merit given by the respondents were converted into ranks by using the following formula:

$$\text{Percent position} = \frac{100\,(R_{ij} - 0.5)}{N_j}$$

Where, Rij = Rank given for the i^{th} item by the j^{th} individual

N_j = Number of items ranked by the j^{th} individual.

The percentage position of each rank thus obtained was converted into scores by referring to the table provided by Henry Garrett. Then for each factor the scores of individual sample farmers were added together and divided by the total respondents for whom scores were added. Thus, mean score for each problem was ranked by arranging them in the descending order.

RESULTS AND DISCUSSION

Climate smart practices: For effective management and coping with climate change in Punjab, various popular CSA practices were identified among the sample farmers. Seven CSPs were identified through primary survey of 240 farmers. Though the farmers used multiple practices, but for analysis the study considered the maximum area adopted under respective CSP as the criteria for distributing farmers under each category (Table 1). The proportion of farmers adopting CSP revealed that major adaptation was short duration varieties like PR126, PR121, PR128 etc of paddy crop which take almost 110 to 120 days for maturity and leaves ample time to manage huge paddy straw. The main CSP adopted during kharif season were SDV, LLL and DSR. On the other hand SS, ZT, HS and B were adopted during *rabi* season (Table 2). The direct seeded rice was followed by only 17.51 per cent of the farmers. The zero tillage (30.57%) and super seeder (33.33%) were the major techniques for in-situ management of paddy straw. The happy seeder was comparatively less popular (20.34%) among the farmers. Farmers have adopted baling (15.82%) as an ex-situ paddy straw management technique.

Out of total sample of 240 farmers, 73.75 % were adopters; in both paddy and wheat crop. In paddy crop 47.08 per cent of the adopters used short duration varieties followed by laser land leveler (13.75%) and direct seeded rice (12.91%). In wheat crop 24.58 per cent have adopted

Table 1. Selected villages

District	Villages	Latitude	Longitude
Ropar	Santhua	30°52'05"N	76°22'43"E
	Katlour	30°53'14"N	76°22'34"E
Sangrur	Kanoi	30°11'33"N	75°51'19"E
	Dhandoli kalan	30°03'27"N	75°55'45"E
Fategarh Sahib	Khanpur	30°38'21"N	76°21'51"E
	Harbanspura	30°38'24"N	76°20'34"E
Patiala	Saholi	30°46'27"N	75°41'12"E
	Bolarkalan	30°17'49"N	76°30'18"E
Mansa	Uddat Bhagatram	29°54'10"N	75°19'49"E
	Mallakpur	30°02'35"N	75°25'23"E
Muktsar	Doda	30°23'04"N	74°38'15"E

Table 2. Adoption pattern of CSA practices as adaptation of climate change (Multiple response)

Particulars	Percentage
Short Duration varieties (SDV)	63.84
Laser Land Leveling (LLL)	18.64
Direct Seeded Rice (DSR)	17.51
Super Seeder (SS)	33.33
Zero Tillage (ZT)	30.57
Happy Seeder (HS)	20.34
Baling (B)	15.82

super seeder for sowing followed by zero tillage (22.50%) and happy seeder (11.67%).

The main reason for adopting climate-smart technologies was the high cost associated with deepening borewells (45.93) (Table 3). This reflected the challenges that farmers faced in maintaining access to groundwater for irrigation, which often involves significant high costs for borewell maintenance and deepening. The second reason for the adoption of CSPs was the expectation of achieving high crop yields. This indicated that farmers are inclined to adopt technologies that promise enhanced productivity and income. This was followed by effective use of agricultural inputs, such as fertilizers, pesticides, and labour scarcity, which ranks fourth. These results emphasized the economic, productivity, and resource management considerations that drive the adoption of climate-resilient technologies among Punjab farmers. The prioritization of these factors underscored the significance of addressing challenges related to input costs, labor availability, and yield enhancement in agricultural practices

Dissemination of information: The majority of sample farmers having average Garrett's score of 59.15 indicated that they predominantly used social media platforms such as YouTube, WhatsApp, and Facebook to gather information about climate-smart practices (Table 4). These digital platforms seem to be the most popular and accessible followed by Television he print media, including newspapers and agricultural magazines like "Kheti Sandesh" and "Changi Kheti" constituted the third major source of information with average Garrett's score of 42.16. Radio ranked fourth in terms of being a source of information for climate-smart practices. These results emphasized the economic, productivity, and resource management considerations that drive the adoption of climate-resilient technologies among Punjab farmers. The prioritization of these factors underscored the significance of addressing challenges related to input costs, labor availability, and yield enhancement in agricultural practices.These results emphasized the economic, productivity, and resource management considerations that drive the adoption of climate-resilient technologies among Punjab farmers. The prioritization of these factors underscored the significance of addressing challenges related to input costs, labor availability, and yield enhancement in agricultural practices.

Extension contacts: The role of agricultural extension plays an important role in the adoption decision process of CSPs. The significant proportion of the sample farmers, 74.17 per cent were, engaged with Agricultural Development Officers (ADOs) (Table 5). Among the adopters of CSP, this engagement was even higher, with 86.44 per cent seeking guidance from ADOs. In comparison, 39.68 per cent of non-adopters reached out to them. This was followed by Krishi Vigyan Kendra (KVK) (46.25 per cent) of for offering practical agricultural advice and disseminating new techniques to improve farming practices. Scientists from Punjab Agricultural University (PAU) were approached by 30.42 per cent of the sample farmers, highlighting their significance among farmers. The higher proportion of adopters (34.36%) consulted PAU scientists compared to non-adopters (19.05%) for their expertise in agricultural research and technology dissemination. Farmers had least interactions with Soil Conservation Officers and Horticulture Development Officers. These findings underscored the essential role that various extension officers, experts, and institutions play in disseminating knowledge and facilitating the adoption of climate-smart practices. The higher engagement rates among adopters, especially with ADOs demonstrate the pivotal role of extension services in

Table 3. Reasons for adoption of climate smart practices in Punjab, 2021-22

Particulars	Average Garrett's score	Ranks
High cost of deepening borewell	45.93	I
Expectation of high yield	43.99	II
Labour scarcity	38.33	IV
Effective utilization of inputs	39.30	III

Table 4. Distribution of sample farmers according to source of information, Punjab 2021-22

Particulars	Average Garrett's score	Ranks
Radio	40.62	IV
Television	57.20	II
Social media (*you tube, whatsapp, facebook etc*)	59.15	I
Print media (*newspaper, magazines- kheti sandesh, changi kheti etc*)	42.61	III

Table 5. Distribution of respondents according to their extension contacts, 2021-22 (Numbers)

Particulars	CSP adopters	Non-adopters
Agricultural development officer	153 (86.44)	25 (39.68)
KVK experts	61 (47.46)	27 (42.86)
PAU scientists	61 (34.36)	12 (19.05)
Soil conservation officer	32 (18.08)	9 (14.29)
Horticulture development officer	39 (22.03)	14 (22.22)

Note: Figures in parentheses are percentages to total

Table 6. Constraints faced by sample farmers during a.doption of CSP in Punjab, 2021-22

Particulars	Frequency	Percentage
Low seed germination	77	43.50
More weed occurrence in the fields	87	49.15
More disease and pest infestation	92	51.98
Small land size	78	44.07
Erratic power supply	98	55.37
Non availability of labour	63	35.59
Lack of access to credit	52	29.38
High cost of machinery and other inputs	68	38.42
Lack of machinery at the time of harvesting and sowing of succeeding crop	85	48.02
More time consuming legal formalities in getting subsidies on farm machinery	102	57.63
Poor information dissemination about technologies through limited extension activities	95	53.67

promoting and supporting the adoption of sustainable agricultural techniques.

Constraints faced by sample farmers during adoption of CSP: The most pronounced constraint, affecting more than half of the adopters (57.63%), was the extensive legal paperwork and time-consuming process required to access subsidies for agricultural machinery (Table 6). Erratic power supply emerged as the second major issue (55.37%), causing disruptions to farming operations as inconsistent power availability can adversely impact irrigation, mechanization, and other energy-dependent tasks. Also, the significant portion of farmers (53.67%) faced challenges due to poor information dissemination and limited extension activities about climate resilient agricultural technologies. High weed occurrence, especially in direct seeded rice fields, posed a significant challenge for 49.15 per cent of the CSPs adopters. Many farmers (48.02%) faced issues related to the availability of machinery during crucial phases of harvesting and sowing, impacting operational efficiency. About 43.50 per cent of the CSPs adopters faced challenges with low seed germination underscored the importance of using high-quality seeds and effective planting practices. Limited access to credit posed a challenge for investment in modern agricultural machinery and inputs (29.38 per cent).The financial burden associated with high cost machinery and inputs was a constraint faced by many adopters (38.42%) which affected CSPs adoption. Addressing these issues through policy interventions, technological advancements, and extension activities is crucial to facilitate smoother and more effective adoption of sustainable agricultural practices.

CONCLUSION

The current climate change situation is a clear indication of growing threat for the agricultural sector in India as well as in Punjab state. The study identified the climate smart practices adopted by farmers in Punjab to mitigate the impacts of climate change and the major constraints faced by the farmers during their adoption. The most widely practiced technologies are LLL, SDV, DSR, SS, ZT, HS and B. The study found that digital platforms such as you tube, facebook and whatsapp etc., seem to be the most popular and accessible means for farmers to access up-to-date information regarding CSPs. The major constraints for adoption of climate resilient technologies were more legal paper work, erratic power supply and limited extension activities etc. This calls for redesigning the implementation mechanism of such smart practices in order to enhance adoption of climate resilient technologies. The study suggested that more extension services, financial support to agriculture sector, educational programs for farmers, demonstrating and trainings on new CSP are necessary for making farming more resilient economically and ecologically.

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Optimizing Water and Energy use in Rice Production through Direct Seeding in Punjab, India

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Abstract: Direct Seeded Rice (DSR) presents a sustainable alternative to Puddled Transplanted Rice (PTR), offering significant reductions in water and energy use in rice production. This study rigorously evaluates the effectiveness of DSR in optimizing resource use, lowering production costs, and enhancing energy use efficiency (EUE) in Punjab, a region critically challenged by water scarcity and energy demands. Employing a multi-stage random sampling method across varied agricultural settings in Punjab, the research quantifies inputs such as seeds, fertilizers, water, and fuel, alongside outputs like grain and straw. DSR not only reduces groundwater and energy consumption by approximately 30% compared to PTR but also curtails labor and irrigation costs by up to 20%. The economic analysis highlights reduction in cost per kilogram of rice produced under DSR, reinforcing its financial viability. The broader implications of these results suggest that DSR could play a crucial role in transforming rice cultivation into a more sustainable practice across similar agro-ecological zones. The study indicates viable solution for regions facing environmental and economic challenges due to traditional rice farming methods.

Keywords: Direct seeded rice, Energy, Water use efficiency, Sustainability

The interconnection between agriculture and energy consumption significantly influences agricultural sustainability. This connection necessitates a balanced integration of production, environmental stewardship, and economic viability (Aghaalikhani et al 2013). As global populations increase and demands for food escalate, the strain on natural resources intensifies, threatening the sustainability of agricultural practices. Contemporary agriculture must embrace resource conservation and effective management to produce cleaner, more sustainable outputs (Kumar et al 2019, Basavaligaiah et al 2020). A critical issue facing current agricultural methodologies is the declining efficiency of energy use (EUE), which necessitates the optimization and efficient deployment of energy inputs across various agricultural operations (Kumar et al 2020). In India, where rice serves as the staple diet for 70% of the population and occupies 40 to 45% of the land dedicated to cereal crops, the challenge is to meet escalating demands with reduced energy inputs. The advent of Direct Seeded Rice (DSR) offers a viable solution amidst global water constraints, significantly lowering energy consumption, carbon emissions, and greenhouse gas outputs (Farooq et al 2011, Basavalingaiah et al 2020). Given the potential for enhancing productivity through improved resource management and technological application, particularly in less efficient farming systems, this study explores the implementation and impacts of DSR in the state of Punjab, India. The need for sustainable agricultural practices in Punjab is urgent due to the high water and energy demands of traditional rice farming methods. DSR emerges as a promising solution, aimed at reducing these inputs while maintaining productivity. The primary objective of this study is to evaluate the environmental and economic benefits of adopting Direct Seeded Rice (DSR) over Puddled Transplanted Rice (PTR) in Punjab's agricultural system. Specifically, the study seeks to quantify the reductions in water and energy use, along with the associated cost savings, to assess DSR's potential as a sustainable agricultural practice.

MATERIAL AND METHODS

This study employed a multi-stage random sampling technique to select a representative sample from regions in Punjab with varying adoption rates of Direct Seeded Rice (DSR). The initial focus was on Sri Mukatsar Sahib, identified as the area with the highest DSR coverage. From there, two blocks known for their intensive use of DSR technology, Gidderbaha and Mukatsar, wereselected. Within these blocks, four villages-Kauni (30.1830° N, 74.6590° E) and Doda (30.0830° N, 74.5670° E) from Gidderbaha; Bhullar (30.2210° N, 74.5501° E) and Thandewala (30.2000° N, 74.5167° E) from Mukatsar-demonstrating widespread DSR adoption were chosen for detailed study. The GPS coordinates ensure accurate location identification, facilitating replication and further research.

The sample comprised 120 farmers, including 80 DSR adopters and 40 non-adopters, categorized by different farm sizes. Data collection involved quantifying the inputs, such as seeds, fertilizers, water, and fuel, and the outputs, namely grain and straw, in terms of energy units. This quantification was achieved by applying specific energy coefficients from the "Research Digest on Energy Requirement in Agriculture Sector," published by the Department of Farm Power and Machinery at Punjab Agricultural University (PAU) (Singh and Singh, 2002).A comparative analysis of energy inputs and outputs between DSR adopters and non-adopters was conducted to assess the efficiency and sustainability of the DSR methodology. This approach provided insights into the energy dynamics of DSR versus traditional rice cultivation methods, highlighting the potential benefits and challenges associated with adopting new agricultural technologies.

RESULTS AND DISCUSSION

The significant reduction in energy use observed in DSR fields not only underscores its efficiency but also positions DSR as a critical innovation in the context of global energy challenges (Farooq et al 2011, Basavalingaiah et al 2020). Comparative studies indicate that traditional methods such as PTR consume up to 40% more energy for similar yields (Kumar et al 2019). This drastic improvement presents DSR as a transformative approach capable of addressing the dual challenges of resource scarcity and environmental sustainability.The implementation of direct seeded rice (DSR) in Punjab has demonstrated significant improvements in energy use efficiency (EUE) and resource management compared to traditional puddled transplanted rice (PTR).

Energy Use Efficiency (EUE): DSR exhibited an energy use efficiency of 4.03, which is higher than the 3.56 for PTR. This increase reflects a substantial improvement, with DSR showing a 13.16% reduction in total input energy across all operations measured. The most notable reductions were observed in the consumption of water and electricity-two of the most critical resources in rice cultivation (Singh and Singh 2002, Ahmed et al 2014) (**Table 1**).

Resource utilization: Analysis of water usage revealed that DSR significantly decreases the amount of water needed per cubic meter, costing Rs 8.61 compared to Rs 7.33 for PTRThis reduction is not only a testament to DSR's improved water use efficiency but also aligns with sustainable water management practices, crucial for the agrarian states facing water scarcity issues.In terms of energy consumption, DSR's approach reduces the dependency on non-renewable energy sources traditionally associated with PTR. This reduction is particularly relevant in the context of global efforts to reduce greenhouse gas emissions and enhance the sustainability of agricultural practices.

Economic benefits: The cost of producing one kilogram of rice under DSR was calculated to be Rs 8.43, significantly less than the Rs 9.88 required for PTR. This cost efficiency offers potential for higher profitability among farmers adopting DSR, coupled with the benefit of reducing the environmental impact of their farming practices (Vatta et al 2021). The economic impacts are summarized in Table 2.

Comparative analysis: The economic benefits of DSR, particularly the reduced cost of rice production, have profound implications for policy and practice (Kumar et al 2020). By lowering production costs by 20%, DSR enhances the profitability for farmers, which could drive higher adoption rates. Policy frameworks that support DSR could leverage these economic benefits to promote widespread adoption, potentially transforming agricultural practices regionally. Further, incentives for DSR could align with governmental goals of sustainability and economic development in agriculture.

The results of this study highlight that Direct Seeded Rice (DSR) offers significant advantages over Puddled

Table 1. Operation wise input energy comparison in rice cultivation

Operations	DSR	PTR	% saving in DSR
Nursery raising	0	220.56	7.27
Land preparation*	592.92	952.01	11.84
Transplanting	210.35	83.02	-4.20
Seed	121.82	83.24	-1.27
Fertilizers	8944.44	10675	57.10
Manure	180.72	166.21	-0.47
Micronutrients & others	45.28	35.66	-0.31
Plant protection	802.76	419.66	-12.64
Irrigation	1173.64	1061.32	-3.70
Electricity	7277.90	8654.02	45.41
Harvesting	638.43	667.34	0.95
Total input energy	19988.30	23018.60	100

Table 2. Cost and resource use in DSR vs. PTR

Resource type	DSR cost/use (Rs/Unit)	PTR cost/use (Rs/Unit)	% Change over PTR
Human labour	5354.82	9004.70	-40.53%
Machine labour	3259.48	4106.20	-20.63%
Seed	681.20	394.50	72.63%
Fertilizers	852.76	1011.78	-15.72%
Plant protection	3946.27	2735.00	44.29%
Irrigation	4270.35	5077.80	-15.90%
Total cost	22264.08	26567.54	-16.19%

Transplanted Rice (PTR) in terms of energy, water conservation, and cost efficiency (Bhullar et al 2018). DSR demonstrated higher energy use efficiency, lower water consumption, and reduced production costs, positioning it as a more economically viable and environmentally sustainable method for rice cultivation. These findings align with global efforts to promote sustainable agricultural practices by minimizing resource use and environmental impacts (Farooq et al 2011, Basavalingaiah et al 2020). The adoption of DSR has clear economic benefits, particularly through the reduction in labor, energy, and irrigation requirements (Bandumula et al 2018). The decreased groundwater footprint associated with DSR further strengthens its position as a sustainable solution for regions facing water scarcity. These results suggest that DSR can effectively contribute to resource-efficient rice production while maintaining or even enhancing yield quality.

From a policy perspective, the broader adoption of DSR could support national and international goals of reducing agricultural water and energy consumption, mitigating greenhouse gas emissions, and promoting sustainable farming systems (United Nations Environment Programme 2021). Increased investment in DSR technology, extension services, and farmer training programs is crucial to maximize its benefits across diverse agricultural landscapes. Additionally, government subsidies or incentives may encourage farmers to transition to DSR, facilitating widespread adoption of this eco-friendly alternative to conventional methods.

CONCLUSION

Direct Seeded Rice (DSR) has emerged as a sustainable and resource-efficient alternative to Puddled Transplanted Rice (PTR) in Punjab, offering significant reductions in water and energy consumption while maintaining or enhancing rice yields. This study demonstrates that DSR optimizes resource use, significantly decreasing groundwater usage and input energy, which leads to lower production costs. The adaptability of DSR across diverse rice-growing regions underscores its potential as a transformative technology for sustainable agriculture. By reducing dependence on non-renewable resources, DSR aligns with global efforts to promote environmental sustainability and improve the economic viability of rice farming. Moreover, its adoption helps mitigate the environmental impacts of traditional rice cultivation, such as excessive water use and high carbon emissions. In addition to its ecological advantages, DSR provides economic benefits to farmers, particularly through reductions in labor, irrigation, and energy costs. These advantages make DSR a key solution for regions facing water scarcity and rising energy demands, particularly in Punjab's agriculture sector. DSR represents a robust strategy for sustainable intensification of rice production, offering both economic and environmental benefits across a wide range of agro-ecological conditions.

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Identifying Key Barriers to Resource-Conserving Technology Adoption in Punjab Agriculture

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Abstract: This study investigates the adoption of Resource-Conserving Technologies (RCTs) in Punjab's agriculture, focusing on paddy-wheat and cotton-wheat cropping systems. Despite the environmental and economic advantages of RCTs, such as reduced greenhouse gas emissions, improved soil health, and efficient resource use, adoption rates in Punjab remain uneven. The research identifies key barriers to RCT adoption, including high costs of machinery, inappropriate sowing moisture, and limited crop residue management practices. Data collected from 120 farmers across two districts, Mansa and Sri Muktsar Sahib reveals significant gaps, particularly in the cotton-wheat system where adoption is notably low. The study employs a Resource Conservation Index (RCI) to quantify the extent of RCT adoption and utilizes Garrett's ranking technique to evaluate the problems faced by farmers. Findings indicate that while paddy-wheat farmers show moderate to high adoption levels, cotton-wheat farmers lag behind. To enhance RCT adoption, the study recommends financial incentives, increased availability of machinery, and greater awareness about the benefits of crop residue management. Addressing these barriers is crucial for advancing sustainable agriculture in Punjab and ensuring the long-term viability of its farming systems.

Keywords: Adoption, Constraints, Direct seeded rice, Punjab, Technologies

Resource-Conserving Technologies (RCTs) encompass practices and innovations that enhance the efficiency of resource use in agriculture (Ghosh et al 2017). These technologies are pivotal in advancing sustainable agriculture, particularly in regions like Punjab, where traditional cropping systems, such as paddy-wheat and cotton-wheat, are prevalent. These systems have historically bolstered economic growthbut also raised significant environmental concerns, including groundwater depletion, soil erosion, and air pollution from the burning of crop residues. To mitigate these challenges, a range of RCTs has been introduced, including the happy seeder, super seeder, zero tillage, direct seeded rice, crop residue management, and integrated pest management. The happy seeder is a notable RCT that facilitates resource conservation by integrating several processes. This tractor-mounted machine cuts and lifts rice straw, sows wheat directly into the soil, and then spreads the straw as mulch over the sown area. By providing an alternative to burning rice residues, the happy seeder allows for direct drilling of wheat into both standing and loose residues (Gathala et al 2011). Similarly, the super seeder offers an innovative approach by chopping and lifting rice straw, planting wheat, and covering the area with straw. This technology allows for immediate sowing of wheat after rice harvest, bypassing the need for burning rice residues and enabling planting 7-10 days earlier than traditional methods. The super seeder is designed to be environmentally friendly, enhancing soil productivity while avoiding harm to local flora and fauna (Kathapalia et al 2022). Zero-tillage technology represents another key RCT, characterized by minimal soil disturbance. This approach primarily involves controlling unwanted vegetation through non-mechanical methods or using minimal tillage equipment, thereby reducing tillage operations to essential tasks like traffic and seed-bed preparation. Originating in the 1950s in the United States for pasture renovation, zero tillage has since become a widely adopted practice.

Direct seeding of rice is an alternative method that conserves soil and water by sowing seeds directly in the field, bypassing the traditional transplanting of seedlings. This approach addresses labour shortages and avoids the negative impacts of soil puddling, such as soil structure disruption and reduced permeability (Bhardwaj and Sidana 2014). The increasing scarcity of water and labour is driving farmers to adopt direct-seeded rice over conventional transplanting methods (Rakesh et al 2017). Crop residue management is a crucial RCT aimed at addressing agricultural waste. Traditional residue removal methods are often costly and labour-intensive, leading many farmers to burn crop residues. In response, various in-situ straw incorporation technologies have been recommended, including straw management systems, zero till drills, happy seeders, super seeders, reversible mould board ploughs, rotavators, and rice straw choppers/mulchers (Singh et al 2022). However, adoption of these technologies remains limited due to high costs and the energy required for in-situ incorporation (Singh and Sidhu 2014). Alternatively, paddy straw can be collected and removal of paddy straw from field by using rake and baler and utilizing it for animal feed, mulch, paper production, or biomass energy generation.

These RCTs are designed to lower input costs, conserve water, improve soil fertility, and reduce greenhouse gas emissions. However, the adoption of these technologies in Punjab has been uneven due to socio-economic, technical, and institutional challenges. Therefore, the present study is devised to gather information on adoption status of RCTs, and major problems faced by farmers while adopting these RCTs.

MATERIAL AND METHEODS

Location and sampling procedure: The study was conducted in Punjab, focusing on farmers from Mansa and Sri Muktsar Sahib district using a multi-stage sampling technique. Initially, districts with the highest proportion of paddy, wheat, and cotton cropped areas were chosen. Mansa and Sri Muktsar Sahib were selected. In the second stage, four villages from each district were randomly selected: Ubha, Uddat Bhagat Ram, Guarangana, and Khialamalkpur from Mansa, and Doda, Roranwali, Bhalaina, and Kot Bhai from Sri Muktsar Sahib. In the final stage, a list of farmers adopting various resource conservation technologies (RCTs) was compiled with assistance from KVK scientists and agricultural development officers. The sample farmers were finalised after focused group discussions were done with various panchayat members and progressive farmers. From this t, 15 farmers per village were chosen, ensuring representation of both RCT adopters and non-adopters. The final sample comprised 120 farm households, with 60 focusing on paddy-wheat sequence, and 60 on cotton-wheat sequence.

Data collection: Data collection involved primary sources. Adetailed interview schedule was prepared to align with the study's objectives. This schedule was pre-tested in the study area, leading to revisions to correct redundancies and address missing information. Primary data were gathered through personal interviews using the revised schedule, focusing on major RCTs and their constraints for paddy, wheat, and cotton crops during the 2021-22 agricultural year.

Construction of resource conservation Index (RCI): Resource conservation index (RCI) was constructed through summative method by taking into account method adopted for sowing in paddy, crop residue management of paddy and method adopted for sowing of wheat in paddy-wheat sequence and method adopted for cultivating cotton, method adopted for sowing wheat in case of cotton-wheat sequence (Table 1).

Resource conservation index for paddy-wheat (RCI_{PW}) = method adopted for sowing in paddy + crop residue management of paddy + method adopted for sowing of wheat)

Resource conservation index for cotton-wheat (RCI_{CW}) = method adopted for cultivating cotton +method adopted for sowing wheat.

Garrett ranking: This method was used to evaluate the problems faced by farmers for adoption of RCTs. The farmers were asked to rank the given problem according to the magnitude of the problem. The orders of merit given by the respondents were converted into ranks by using the following formula:

$$\text{Percent position} = \frac{100\,(R_{ij} - 0.5)}{N_j}$$

Where,

R_{ij}= Rank given for the ith item by the jth individual

N_j= Number of items ranked by the jth individual

Table 1. Construction of resource conservation Index

Indicators of resource conservation	Assigned score	Minimum score	Maximum score
Paddy-wheat crop rotation			
Method adopted for sowing paddy (A)	0 if puddled transplanted rice 1 if direct seeded rice	0	1
Crop residue management of Paddy (B)	0 if not managed 1 if managed	0	1
Method adopted for sowing wheat (C)	0 if conventional tillage 1 if modern tillage	0	1
Resource Conservation Index for paddy-wheat (RCI_{PW}) = A+B+C		0	3
Cotton-wheat crop rotation			
Method adopted for cultivating cotton (D)	0 if not integrated pest management 1 if integrated pest management	0	1
Method adopted for sowing wheat (E)	0 if conventional tillage 1 if modern tillage	0	1
Resource Conservation Index for cotton-wheat (RCI_{CW}) = D+E		0	2

The percentage position of each rank thus obtained was converted into scores by referring to the table provided by Henry Garrett. Then for each factor the scores of individual sample farmers were added together and divided by the total respondents for whom scores were added. Thus, mean score for each problem was ranked by arranging them in the descending order.

RESULTS AND DISCUSSION

The constructed RCI ranged between 0 (representing entirely non-adopters of modern farming practices for paddy-wheat and cotton-wheat) and 2 (representing complete adopters of resource conservation technologies for paddy-wheat and cotton-wheat). Hence, RCI has as a scale to measure the extent of modern farming practiced by the farmers in the study area. Based on the points scored on the RCI scale, farmers were classified into four groups (Table 2). Farmers were categorized based on their adoption of RCTs for two different cropping systems: paddy-wheat and cotton-wheat. It provides a comparative view of the extent of RCT adoption among farmers in these systems by dividing them into four groups: non-adopters, fair adopters, good adopters, and exceptional adopters.

For paddy-wheat farmers, more diverse range of adoption levels. The 26.67% of farmers are non-adopters, meaning thereby that they do not engage with RCTs. The 23.33% of the farmers are fair adopters, showing moderate use of these technologies. The largest group, comprising 35% of the farmers, are classified as good adopters, indicating that a significant number of farmers have integrated RCTs well into their practices. The remaining 15% are exceptional adopters, representing the highest level of commitment to resource conservation. In contrast, the adoption of RCTs in the cotton-wheat system is less advanced. More than half (55%) of the farmers fall under the non-adopter category, indicating a limited embrace of RCTs. Only 45% of the cotton-wheat farmers came under the category of are considered fair adopters. There are no farmers in the cotton-wheat system who qualify as good or exceptional adopters. This contrast suggests that while paddy-wheat farmers in the study area are making more substantial strides in adopting RCTs, cotton-wheat farmers are lagging behind. This indicates clear need for targeted efforts to improve RCT adoption in cotton-wheat cultivation, possibly through increased awareness, technical support, or incentives.

Table 2. Categories of paddy-wheat and cotton-wheat growers on the basis of extent of resource conservation technologies adoption

Categories	Paddy-wheat		Cotton-wheat	
	RCI_{PW}	Percentage	RCI_{CW}	Percentage
Non adopters	0	26.67	0	55
Fair adopters	1	23.33	1	45
Good adopters	2	35	2	0
Exceptional	3	15	-	-

In DSR in paddy, only 23.33% of farmers adopted the technology, leaving 76.67% still relying on traditional methods. For crop residue management (CRM) in paddy, the adoption is slightly better, with 35.83% of farmers implementing it, but a majority (64.17%) have not. Modern tillage in wheat shows an equal adoption rate, where 50% of farmers have adopted the technique and 50% have not. High level of adoption among farmers regarding Super Seeder which constitute of 53.33 per cent was seen in Haryana also (Kathpalia et al 2023). For IPM for cotton, 38.33% of farmers have adopted the practice, while the remaining 61.67% have not. This variation in adoption rates highlights the challenges in promoting RCTs, particularly in paddy and cotton cultivation, and underscores the need for further interventions to improve technology uptake among farmers.

Problems Faced in Adoption of RCTs in Paddy-Wheat and Cotton-Wheat Crop Rotation

Happy seeder / super seeder: Among the sample data, based on farmer's experience, the major problem encompassed by the farmers for adoption of happy seeder/super seeder was high cost of machinery and high inappropriate moisture at sowing. Inappropriate moisture at sowing is also correlated with another main problem i.e., lower seed germination indicated by 47.75 Garrett's score (Table 3). Singh et al (2022) stated in their study that 35 per cent farmers were facing the problem of shortage of hired machinery.

Zero till drill: In adoption of zero till drill, the major problem reported by farmers was low germination of seed having

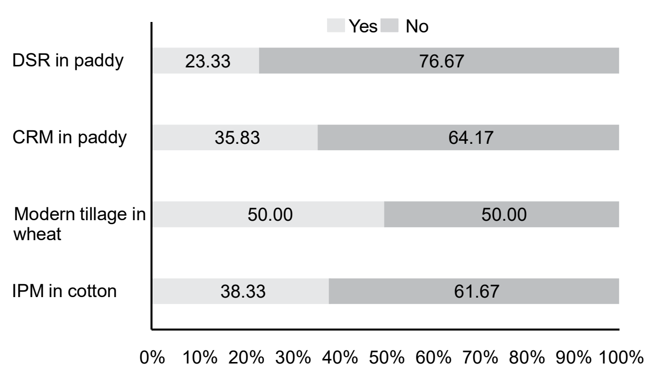

Fig. 1. Paddy, wheat and cotton cultivators with respect to indicators of resource conservation technologies

57.75 average score followed by non-availability at the time of sowing. Inappropriate moisture at sowing was observed to be the least problematic parameter in adoption of zero till drill with an average score of 38.50, followed by high cost of zero till drill with 48.08 Garrett's score.

Direct seeded rice technology: Among various DSR problems faced by sample farmers, less yield of crop was observed to be top ranked with 68.83 Garrett's average score. The second and third rank was given to increased cost of production due to more requirements of herbicides and low seed germination. More pesticide requirement was another problem in adoption of direct seeded rice.

Table 3. Problems faced by farmers for adoption of RCTs in paddy-wheat and cotton-wheat crop rotation, Punjab (2021-22)

Problems	Garrett's average score	Rank
Problems in adoption of happy seeder / super seeder		
High cost of machinery	67.50	I
Inappropriate moisture at sowing	54.42	II
Low seed germination	47.75	III
Lack of technical know how	40.67	IV
Loose straw affects functioning of machinery	39.50	V
Problems in adoption of zero till drill		
Low seed germination	57.75	I
Non availability of machineat the time of sowing	54.58	II
Unwillingness to adopt	54.08	III
High cost of zero till drill	48.08	IV
Inappropriate moisture at time of sowing	38.50	V
Problems in adoption of direct seeded rice technology		
Less yield of crop	60.83	I
Increased cost of production due to more requirement of herbicides	51.92	II
Low seed germination	51.00	III
Requirement of specific machinery	44.25	IV
DSR requires more pesticides	43.08	V
Problems in adoption of IPM in cotton		
Does not fulfil the complete insecticide requirement	55.22	I
More infestation of Insect pests	54.83	II
Less knowledge	50.17	III
Labour intensive practice	48.97	IV
Complicated procedure	42.97	V
Problems in adoption of crop residue management		
Extra cost involved	70.42	I
Shortage of hired machine	59.17	II
No market value of paddy straw	46.50	III
Delays sowing of preceding crop	43.75	IV
Shortage of skilled labour	29.17	V

IPM in cotton: According to Garrett's ranking technique IPM in cotton does not fulfill the complete insecticide requirement occupied the first rank with an average score of 55.22 followed by the problem of more infestation of insect pests. Labour intensive practice and complicated procedure were perceived as general problems by the farmers in IPM adoption. Previous studies have highlighted similar challenges with IPM adoption, noting increased risks of inadequate pest control, higher labour costs, and the need for new equipment (Kudusk Per 2023).

Crop residue management: Problems faced by the sample farmers in adoption of crop residue management varied with a huge difference in its average score. Non-adopter farmers reported that extra cost involved in crop residue management was one of the major constraints. Shortage of machines like bailer, paddy chopper and others were ranked second with an average score of 59.17. Absence of paddy straw's market value and delay in sowing of proceeding crop was regarded as other challenges faced by the farmers. Shortage of skilled labours with an average least Garrett's score of 29.17 was accounted as other issue among the farmers. Chopra and Bansal (2022) mentioned that labour shortage at the time of harvesting and the costly process of cleaning the field after harvesting paddy crop are other vital determinants leading to crop residue burning cases in Punjab.

Policy implications: To encourage the rapid adoption of this technology financial help should be provided to farmers for motivating them to adopt RCTs and timely-availability of machinery for ex-situ management for reducing the carbon footprint. Low availability of ex-situ machines such as balers and storage infrastructure is another reason for low adoption of ex-situ management practices. Efforts should be made for increasing the demand of paddy straw as a raw material for industries, new inventions and alternative technologies e.g. bio char production, raw material for power generation and paper mill industry, bedding material for livestock. For maximum adoption of paddy residue management technology, there should be more availability of paddy residue management machines at co-operatives, raising awareness among farmers regarding importance of crop residues in conservation agriculture and providing incentives to the adopter farmers who adopt stubble management technology. Similarly, for modern tillage of wheat, super seeder and happy seeder shall have to be made available to the farmers especially among small and marginal farmers on custom-hiring basis through co-operatively managed machinery service centres. There is a need for capacity building of farmers for effective management of weed and pest in DSR. There is a need to improve efficiency of agricultural pump sets to improve water use efficiency which lowers carbon emissions, increasing fertilizers N use efficiency by reducing the use of N based fertilizers, reducing fossil fuels by doing less tillage and prevention of paddy residue burning by using various ex-situ and in-situ technologies. These all mitigation strategies will help reduce agricultural GHG emissions in the state.

CONCLUSION

The study identifies critical gaps in the adoption of RCTs in Punjab's paddy-wheat and cotton-wheat cropping systems. Despite their clear advantages such as reducing environmental impact, improving resource use efficiency, and enhancing soil health, RCT adoption remains suboptimal. Key challenges include high machinery costs, suboptimal moisture levels at sowing, and inadequate crop residue management. Adoption trends in the paddy-wheat system show progress, particularly with practices like direct seeded rice and happy seeder gaining wider acceptance among farmers. However, adoption in the cotton-wheat system lags, highlighting the need for targeted interventions. Addressing barriers through financial incentives, improving machinery access, and raising awareness about the benefits of crop residue management are essential for wider RCT adoption. Supporting innovations in crop residue utilization and improving water use efficiency can further reduce emissions and promote sustainability. By implementing these strategies, Punjab can progress toward a more sustainable agricultural system, balancing environmental, economic, and resource conservation goals.

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Impact of Anthropogenic Activities on Mavala Lake's Water Quality In Adilabad, Telangana, India

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Abstract: This study evaluates the physicochemical parameters of Mavala Lake, located in Adilabad District, Telangana State, to assess water quality variations and pollution indicators from February to July 2023. Water samples were collected from two sites: Site-A, positioned centrally, and Site-B, near the shoreline, to capture spatial variations in water quality. Mavala Lake exhibited higher temperatures and pH levels, suggesting a more stressed aquatic environment. Elevated EC, turbidity, and nutrient levels, particularly in phosphate and nitrate, were observed, reflecting increased pollution and potential eutrophication. The reduced DO levels and elevated BOD and COD values, pointed to significant organic and inorganic pollution. These findings highlight the lake's vulnerability to pollution and underscore the need for improved management practices. The results emphasize the importance of continuous monitoring and targeted interventions to address pollution sources and improve the lake's environmental conditions, thereby supporting sustainable water management and conservation efforts.

Keywords: Mavala pond, Adilabad, Physicochemical parameters, Biochemical oxygen demand, Chemical oxygen demand, Dissolved oxygen

Mavala Lake, located in Adilabad District, Telangana State, has emerged as a critical subject of environmental concern due to increasing pollution and its impacts on water quality. Over recent years, the lake has faced growing pressures from agricultural runoff, industrial discharge, and urban development, which contribute to significant changes in its physicochemical properties. The importance of monitoring such changes has been emphasized by recent studies, highlighting the need to understand the extent of human influence on freshwater ecosystems (Kumar et al 2009). Anthropogenic activities can lead to nutrient enrichment, which fosters algal blooms and deteriorates water quality, thus compromising the health of aquatic life and disrupting ecological balance (Manivasakam et al 2003, Shukla et al 2019). Understanding these impacts is essential for developing effective management practices and ensuring the sustainability of the lake's ecosystem. Physicochemical parameters such as temperature, pH, electrical conductivity (EC), and turbidity are crucial for assessing water quality and ecological health. Variations in these parameters can provide insights into the level of pollution and the degree of environmental stress affecting the lake. The elevated EC and turbidity levels often indicate increased runoff and the presence of suspended particles, which can adversely affect water quality and aquatic habitats (Lamma et al 2018). Temperature and pH fluctuations also play a significant role in determining the lake's health, as they influence the solubility of nutrients and the overall biological activity within the water body (Arulnagai et al 2021). Effective monitoring of these parameters helps in understanding the dynamics of pollution and its effects on aquatic life.

This study aims to provide a detailed evaluation of Mavala Lake's physicochemical parameters over a six-month period, with a focus on identifying trends and potential indicators of pollution. By systematically analyzing data from various sampling sites, the research seeks to offer a comprehensive assessment of the lake's water quality. Such an analysis is critical for detecting pollution sources and assessing the effectiveness of current management strategies (Bihari et al 2010). Previous research has demonstrated that continuous monitoring and data collection are vital for mitigating the adverse effects of pollution and ensuring the protection of aquatic ecosystems (Srithar et al 2006). This study will contribute valuable insights into the environmental status of Mavala Lake and support efforts to enhance water quality and ecosystem health.

MATERIAL AND METHODS

Sampling sites: The present investigation was conducted in Mavala Pond, located in Adilabad District, Telangana State, with water samples collected over a six-month period from February 2023 to July 2023. Two specific sites within the pond were selected for sampling to ensure a comprehensive analysis of the water quality. Site-A, situated at coordinates 19°37'52"N and 78°30'38"E, represents the central region of the pond, while Site-B, located at 19°37'52"N and 78°30'43"E, is positioned closer to the pond's shoreline. These sites were chosen to capture the potential spatial variability in physicochemical parameters within the pond, allowing for a detailed assessment of water quality trends and their possible environmental implications over the study period. Site-A is characterized by deeper waters and is likely to reflect the general water quality of the lake's main body, influenced by both natural processes and human activities. Site-B is situated closer to the shoreline, where the water is shallower and more directly impacted by runoff and nearshore activities. The selection of these two sites allows for the assessment of potential differences in water quality between the central and peripheral areas of Mavala Lake, providing valuable insights into the spatial distribution of pollutants and other physicochemical parameters within the lake.

Sampling and sample collection methods: The sampling and sample collection methods for this study were designed to ensure the accurate representation of water quality in Mavala Lake. Water samples were collected monthly from February 2023 to July 2023, covering both pre-monsoon and monsoon seasons. Samples were taken from two predetermined sites within the lake-Site-A (central area) and Site-B (shoreline area)-to capture potential spatial variations in water quality. The collection process followed standard procedures as outlined by APHA (2017). At each site, water samples were collected at a depth of approximately 30 cm below the surface using pre-cleaned polyethylene bottles. To ensure consistency, samples were collected between 8:00 and 10:00 AM, minimizing the influence of diurnal variations in water quality. The collected samples were immediately stored in iceboxes and transported to the laboratory for analysis. Parameters such as temperature, pH, and dissolved oxygen were measured on-site using portable instruments, while other parameters were analyzed in the laboratory.

Physicochemical parameters: To assess the physicochemical parameters, a series of chemical and physical measurements were conducted in accordance with established standard methods. Key parameters such as electrical conductivity (EC), total hardness (TH), dissolved oxygen (DO), and major anions like chloride (Cl^-), nitrate ($NO3^-$), and phosphate (PO_4^{3-}) were evaluated using protocols detailed by the APHA (2005) and Khadka et al (2021). In-field measurements of pH, EC, and turbidity were carried out with a multi-parameter instrument to ensure precise readings. Biological Oxygen Demand (BOD) was determined by incubating the samples in the dark at 20°C for five days and then calculating the BOD by subtracting the final DO concentration from the initial DO concentration, as recommended by Olompande et al (2011). Chemical Oxygen Demand (COD) was measured using potassium dichromate as an oxidizing agent, following the method described by Bagalwa et al (2006). Collected water samples were promptly transported to the laboratory in a cooler with ice to preserve their integrity. If immediate analysis was not feasible, samples were stored at 4°C in a refrigerator to prevent any changes in their chemical properties.

Statistical analysis: Statistical analysis of the collected data was conducted using MS Excel.

RESULTS AND DISCUSSION

Physicochemical parameters: Mean physicochemical parameters of two sites of Mavala Lake water in different months are presented in Table1.

Temperature: The temperature of Mavala Lake water showed significant variation from February to July 2023, ranging from 24.0°C in February to a peak of 37.0°C in May, slightly surpassing the standard permissible limit. This indicates the influence of seasonal changes, with the highest temperatures in March and May (30.0°C and 37.0°C, respectively). The cooling effect observed in July (30.0°C) can be attributed to the onset of monsoon rains, which typically lead to a decrease in ambient temperatures. These fluctuations suggest that Mavala Lake experiences considerable thermal variations, which may impact aquatic life, as temperature changes can affect the solubility of oxygen and other critical factors for ecosystem health (Vijay Kumar et al 2024).

pH: The pH levels of Mavala Lake water varied slightly over the months, ranging from 7.9 in March to 9.5 in July, indicating a trend towards alkalinity. The highest pH value recorded in July (9.5) is above the recommended upper limit of 8.5 for freshwater bodies, suggesting a potential risk of alkalinity-related issues, such as reduced biodiversity and altered chemical processes in the water. The consistency in pH values throughout the months implies a relatively stable chemical environment, albeit one that may be becoming increasingly alkaline over time. The rising pH levels could be due to factors like increased photosynthetic activity by algae, .Arulnangai et al (2021) also observed algal blooms in similar lakes led to higher pH due to carbon dioxide uptake.

Electrical Conductivity (EC): The electrical conductivity (EC) in Mavala Lake displayed a steady upward trend from February to July 2023, ranging from 169.9 µS/cm in February to 195.0 µS/cm in July. These values within the acceptable range of 20-500 µS/cm, suggest increasing levels of dissolved salts and ions in the water. The rise in EC is particularly notable in April and May, with values reaching 187.3 and 198.8 µS/cm, respectively, indicating a higher concentration of ionic substances, possibly due to evaporation during the warmer months or agricultural runoff. The standard deviations remain moderate, suggesting consistent EC levels across the sampling period. However, the overall increase in conductivity could signal potential water quality issues, such as the intrusion of pollutants or salinity from surrounding areas. Monitoring these levels is crucial, as high EC can affect the water's suitability for drinking, irrigation, and aquatic life (Vijaya Kumar et al 2024).

Turbidity: The turbidity levels in Mavala Lake water exhibited moderate fluctuations across the months, with values ranging from 26.9 NTU in February to a low of 17.9 NTU in July. These values reflect the presence of suspended particles in the water, such as silt, algae, and organic matter. The highest turbidity recorded in February (26.9 NTU) suggests a higher concentration of particulates, possibly due to soil erosion or runoff from nearby areas. The decrease in turbidity towards the monsoon season, particularly in July, is indicative of the settling of particles as a result of reduced surface runoff or dilution by rainwater. There was slight fluctuating turbidity level throughout the months. The turbidity values are not excessively high, but still necessitate regular monitoring, as increased turbidity can reduce light penetration, affecting photosynthesis and the overall health of aquatic ecosystems (Asha et al 2007)

Total hardness (TH): The total hardness (TH) of Mavala Lake water varied notably over the six months, with values ranging from 119.1 mg/L in July to peak of 176.6 mg/L in April. These levels, while within the permissible limit of 300 mg/L, indicate fluctuations in the concentration of calcium and magnesium ions, which contribute to water hardness. The highest TH in April suggests an increased mineral content, possibly due to evaporation and concentration of dissolved salts during the hotter months. The lower values in June and July may result from the dilution effects of incoming rainwater during the monsoon season. e TH levels are not critically high, continuous monitoring is essential to prevent potential scaling in water systems and to ensure the water remains suitable for domestic and agricultural use (Krishnamurthy and Selva Kumar 2010).

Total Alkalinity (TA): Total alkalinity (TA) in Mavala Lake showed significant fluctuations throughout the observation period, with values ranging from 111.0 mg/L in June to 209.1 mg/L in April. These values, which exceed the standard limit of 250 mg/L at times, suggest a varying ability of the water to neutralize acids, which is crucial for maintaining pH stability. The peak in April could be attributed to increased carbonate and bicarbonate ions due to evaporation and the concentration of these ions in the water. Conversely, the drop in TA in May and June suggests dilution effects, likely from monsoon rainfall. The variability in TA, as reflected by the standard deviations, indicates the lake's changing chemical composition, which could impact aquatic life by affecting the availability of nutrients and the overall buffering capacity of the water. Regular monitoring is advised to ensure the lake's

Table 1. Physicochemical parameters of Mavala Lake water**.**

Physicochemical parameters (Standard values)	Physicochemical parameters in different months					
	February	March	April	May	June	July
Temperature (<37)	24.0 ± 1.6	30.0 ± 2.8	33.5 ± 2.0	37.0 ± 1.7	35.5 ± 3.2	30.0 ± 2.3
pH (6.5-8.5)	8.9 ± 0.7	7.9 ± 0.3	8.1 ± 0.9	8.4 ± 0.7	8.6 ± 0.4	9.5 ± 0.3
EC (uS/cm) (20-500)	169.9 ± 12.8	171.2 ± 9.8	187.3 ± 14.1	198.8 ± 15.2	192.2 ± 14.1	195.0 ± 9.2
Turbidity (NTU)	26.9 ± 4.2	20.6 ± 6.5	24.9 ± 2.2	23.4 ± 4.1	21.9 ± 3.2	17.9 ± 4.5
TH (mg/L) (300)	141.6 ± 11.4	163.6 ± 9.2	176.6 ± 8.2	147.4 ± 9.0	128.6 ± 12.1	119.1 ± 10.3
TA (mg/L) (250)	196.4 ± 12.7	171.1 ± 10.1	209.1 ± 7.0	122.0 ± 11.6	111.0 ± 10.3	206.6 ± 6.5
Chloride (mg/L) (250)	73.4 ± 9.9	78.6 ± 8.1	81.7 ± 4.4	83.1 ± 10.1	74.0 ± 5.0	76.7 ± 11.6
Nitrate (mg/L) (<45)	1.21 ± 0.04	1.54 ± 0.22	0.44 ± 0.01	0.54 ± 0.003	0.52 ± 0.001	0.53 ± 0.01
Phosphate (mg/L) (<4)	0.98 ± 0.04	1.65 ± 0.06	2.97 ± 0.09	3.52 ± 0.10	1.76 ± 0.08	1.21 ± 0.03
DO (mg/L) (6)	6.7 ± 1.2	2.0 ± 0.3	3.7 ± 0.5	4.8 ± 1.2	5.6 ± 1.1	6.2 ± 0.5
BOD (mg/L) (0-50)	12.8 ± 3.1	10.2 ± 2.2	15.2 ± 2.9	13.6 ± 2.0	15.4 ± 3.1	14.7 ± 2.0
COD (mg/L) (10-20)	35.8 ± 4.8	23.8 ± 4.3	41.6 ± 2.1	35.5 ± 5.4	29.2 ± 7.0	22.7 ± 3.1

Values are presented in mean ± SD.

alkalinity remains within safe limits for its ecological and human uses (Kulkarni et al 2008, Mathur et al 2010).

Chloride: The chloride levels in Mavala Lake water ranged from 73.4 mg/L in February to 83.1 mg/L in May, with the highest concentration observed during the pre-monsoon months. These values, below the permissible limit of 250 mg/L, indicate the presence of chloride ions, which can originate from both natural sources, such as the weathering of rocks, and anthropogenic activities, such as agricultural runoff or wastewater discharge. The increase in chloride levels in May may be due to the concentration of salts during the dry season when water levels are lower. The subsequent decrease in June and July suggests dilution by rainwater. The standard deviations indicate a moderate level of variability, with the most significant changes occurring between March and May. Although the chloride levels are within acceptable limits, should be monitored regularly to prevent potential issues related to salinity, which can affect the taste of water and its suitability for irrigation (Rohankar et al 2009).

Nitrate: Nitrate levels in Mavala Lake remained relatively low and stable throughout the six-month period, with values ranging from 0.44 mg/L in April to 1.54 mg/L in March. These levels are well within the permissible limit of 45 mg/L, indicating minimal nitrate pollution, which is often associated with agricultural runoff or sewage discharge. The slight increase in nitrate levels in March could be attributed to seasonal agricultural activities, where fertilizers are more likely to be applied. The current nitrate levels do not pose a significant risk to water quality, ongoing monitoring is essential to ensure that they remain low, as elevated nitrate concentrations can lead to eutrophication, resulting in excessive algae growth and oxygen depletion, which can harm aquatic life (Singh et al 2013).

Phosphate: Phosphate levels in Mavala Lake showed considerable variation from February to July 2023, ranging from 0.98 mg/L in February to a peak of 3.52 mg/L in May. These fluctuations indicate a dynamic nutrient environment within the lake, with the highest phosphate levels recorded during the pre-monsoon months. The elevated levels in April and May could be due to increased agricultural runoff or the release of phosphate-rich effluents into the lake. Although the values remain within the acceptable limit of 4 mg/L, the observed peaks suggest potential risks of eutrophication, where high phosphate levels can lead to excessive algal blooms, reducing oxygen availability and harming aquatic life. The standard deviations reflect moderate variability, with the most significant changes occurring between March and May. Regular monitoring and management of phosphate sources are crucial to maintaining the lake's water quality and preventing long-term ecological damage (Sivalingam et al 2013).

Dissolved Oxygen (DO): Dissolved oxygen (DO) levels in Mavala Lake exhibited fluctuations, ranging from a low of 2.0 mg/L in March to a high of 6.7 mg/L in February. These values reflect the lake's capacity to support aquatic life, with higher levels typically indicating better water quality. The drop in DO during March and April, significantly below the standard limit of 6 mg/L, suggests periods of oxygen stress, likely due to increased organic matter decomposition or algal blooms, which consume oxygen. The study indicate significant variability, particularly during the warmer months, when higher temperatures can reduce the solubility of oxygen in water. The gradual increase in DO levels towards July suggests some recovery, possibly due to cooler temperatures and increased mixing from rainfall. Maintaining adequate DO levels is essential for the health of aquatic ecosystems, and ongoing monitoring is necessary to prevent periods of hypoxia, which can lead to fish kills and biodiversity loss (Bagade and Belagali 2010).

Biochemical Oxygen Demand (BOD): The biochemical oxygen demand (BOD) of Mavala Lake water fluctuated between 10.2 mg/L in March and 15.4 mg/L in June, with the highest observed during the warmer months. These levels, while within the acceptable range of 0-50 mg/L, indicate varying degrees of organic pollution, where higher BOD values suggest an increased presence of biodegradable organic matter in the water. The peak in June could be attributed to the accumulation of organic materials, such as plant debris or wastewater discharge, which depletes oxygen levels as microorganisms break down these substances. There was moderate variability in BOD levels, with significant changes occurring between March and April. The current BOD levels are not critically high but should be monitored closely, as elevated BOD can lead to oxygen depletion, affecting aquatic life and overall water quality. Preventive measures, such as controlling pollutant sources, are recommended to maintain balanced BOD levels (Bihari Singh et al 2010).

Chemical Oxygen Demand (COD): Chemical oxygen demand (COD) showed considerable variation over the months, with the highest level recorded in April (41.6 mg/L) and the lowest in July (22.7 mg/L). These values exceed the standard limit of 20 mg/L, indicating the presence of significant amounts of organic and inorganic pollutants in the lake. The peak in April suggests an increased load of oxidizable pollutants, possibly due to agricultural runoff or industrial discharge. The subsequent decrease in June and July could be attributed to the dilution effect of rainwater during the monsoon season. There was notable variability, particularly during the pre-monsoon months, when pollutant concentrations tend to be higher. High COD levels are a cause for concern, as they reflect the lake's reduced ability to support aquatic life and its increased susceptibility to pollution. Regular monitoring and effective pollution control measures are essential to mitigate the impact of these pollutants on the lake's ecosystem (Dwivedi and Pathak 2009).

CONCLUSION

The study of Mavala Lake's physicochemical parameters from February to July 2023 reveals significant environmental challenges, particularly when compared with others Lake. Mavala Lake exhibited higher temperatures, elevated pH, increased electrical conductivity, and turbidity levels, all indicative of a more polluted and stressed aquatic environment. The elevated phosphate concentrations and lower dissolved oxygen levels, especially during the pre-monsoon period, suggest a heightened risk of eutrophication and oxygen depletion, which could severely impact aquatic life. These findings highlight the urgent need for effective pollution control and water management strategies to mitigate the impact of agricultural runoff, industrial discharge, and other anthropogenic activities on Mavala Lake. Regular monitoring and intervention are essential to preserve the lake's ecological balance and prevent further environmental degradation.

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Assessment of Groundwater Extraction and Water Footprints In Punjab

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Abstract: This study investigates regional disparities in groundwater extraction and irrigation practices across Punjab. A total of 500 farmers from 20 villages were surveyed, with data collected on borewell depth, water levels, motor capacity, and water productivity. In central Punjab districts i.e. Sangrur, farmers heavily rely on deep submersible pumps and long-duration crop varieties. Sangrur exhibits the deepest borewells (355 ft) and highest motor capacities (19.22 hp), reflecting severe groundwater extraction. Conversely, southwestern districts such as Bathinda and Fazilka use centrifugal pumps and benefit from canal water to address groundwater scarcity and quality concerns. Water footprints vary significantly, with Bathinda and Sangrur exhibiting the highest for paddy (2366 and 2245 l/kg respectively). Sangrur shows a high footprint for Basmati rice (3357 l/kg) and Bathinda exhibits highest for wheat (760 l/kg). Water productivity varies across districts, higher productivity observed for paddy in Hoshiarpur (0.605 kg/m³) and Rupnagar (0.541 kg/m³). For wheat, water productivity was higher in Sangrur (1.658 kg/m³), Hoshiarpur (1.603 kg/m³), and Rupnagar (1.597 kg/m³). The study emphasizes the urgent need for region-specific water management strategies, including promoting short-duration crops, enhancing canal infrastructure, and implementing artificial groundwater recharge.

Keywords: Groundwater, Water footprint, Tubewell, Water productivity

Freshwater is essential for agriculture, but its availability is increasingly under pressure due to the rising population, urbanization, and growing irrigation demands. While 75% of Earth's surface is covered by water, only 2.7% of it is freshwater. The world's population depends on just 0.75% of the total global water resources. Although freshwater resources are renewable, their availability is limited both geographically and temporally. India holds only 4% of the world's freshwater, with 85% of it being used in agriculture (Dhawan 2017). Punjab has a total of 50.36 lac hectares geographical area and 83 per cent area under cultivation and cropping intensity about 191.7 percent. Before independence, Punjab was known as the "Land of Five Rivers" due to the Sutlej, Beas, Ravi, Chenab, and Jhelum rivers. Post-independence, only the Sutlej, Ravi, and Beas flow through the region. Significant investments were made in irrigation infrastructure, including the construction of dams and reservoirs, along with the expansion and remodeling of the canal network in Punjab. The construction of multipurpose storage dams on Punjab's major rivers has greatly improved water regulation and helped distribute water more evenly throughout the year (Jairath 1985). Punjab has twelve major canals serving both households and agriculture. However, poor management and uneven distribution of canal water have left many farmers dependent on groundwater for irrigation. In Punjab, 99.8% of the cultivated area is irrigated, making it one of the few regions where agricultural productivity is less affected by drought due to its complete reliance on groundwater irrigation. As the demand for irrigation water increases, driven by the country's food security needs, pressure on groundwater resources has intensified, leading to drastic depletion. Punjab now has about 1.53 million tube wells, contributing to the expansion of the net irrigated area (GOP 2023). The state's net annual groundwater availability is 13.83 million acre-feet (MAF), but current extraction is 22.70 MAF, with 21.62 MAF used for irrigation. This represents an over-extraction rate of 164%, leading to a continuous decline in the groundwater table (CGWB 2022).

Once renowned for its abundant water resources, Punjab is now on the brink of a severe water crisis, driven by unsustainable over-reliance on groundwater for irrigation. The state's groundwater reserves are being depleted at an alarming rate, threatening the future of agriculture and water security. This study was planned to shed light on the critical groundwater extraction crisis in Punjab through scientific assessment of groundwater extraction in various crops.

MATERIAL AND METHODS

The study was conducted in five districts of Punjab i.e. Bathinda, Sangrur, Fazilka, Rupnagar, and Hoshiarpur selected from three agro-climatic zones based on the highest acreage of five major crops such as rice, wheat, cotton, maize, and sugarcane during 2019-20. Using a multi-stage sampling method, two blocks from each district and two villages from each block were randomly chosen, resulting in a total of 20 villages. From each village, 25 respondents were selected at random, leading to a total sample size of 500 farmers.

Groundwater extraction: Groundwater extraction was analyzed by gathering information on bore well depth, water level, and motor capacity used by the respondents for crop cultivation.

Water inputs based water footprint (WFP): This referred to the total volume of irrigation water applied by a farmer to produce a crop.

$$WFP_{water\ input} = \frac{\text{Irrigation water applied for i}^{th}\text{ crop per unit area}}{\text{Yield of i}^{th}\text{ crop per unit area}}$$

Water productivity: Water productivity was calculated as the inverse of the WFP.

RESULTS AND DISCUSSION

Sources of irrigation water: This study indicates significant regional disparities in water use practices, groundwater levels, and the associated irrigation infrastructure, reflecting the complex interplay between natural resource availability and agricultural demands. The study reveals that farmers across Punjab primarily depend on groundwater, with the type of borewell varying by region (Table 1).

In Sangrur, Hoshiarpur, and Rupnagar districts, farmers overwhelmingly utilize submersible pumps due to their deeper water tables and limited access to canal water. Conversely, in the southwestern districts of Bathinda and Fazilka traditionally known as the cotton belt, farmers employ centrifugal pumps alongside canal water to offset the scarcity and poor quality of groundwater. The reliance on submersible pumps in central Punjab districts like Sangrur can be attributed to the declining availability of surface water and the inefficiency of canal infrastructure. In contrast, the use of centrifugal pumps in Bathinda and Fazilka indicates a dual dependence on both groundwater and canal water, reflecting regional efforts to manage irrigation needs amidst fluctuating water quality and availability.

Table 1. Distribution of respondents according to the source of irrigation water (Percent)

District	Groundwater		Surface water/ Canal water
	Bore well		
	Submersible	Centrifugal	
Sangrur (n=100)	100	-	15
Hoshiarpur (n=100)	100	-	-
Rupnagar (n=100)	100	-	-
Fazilka (n=100)	40	42	100
Bathinda (n=100)	72	14	100

Groundwater extraction: Groundwater extraction has been assessed on the basis of water level (Table 2) and bore depth (Table 3). In Fazilka district, the water table is relatively shallow, ranging from 21 to 60 feet for most respondents. However, due to its location at the tail end of canal channels, farmers in Fazilka face periodic water shortages, especially during peak cropping seasons. In Bathinda, 45% of fields have water levels between 61 and 100 feet, while 63% of fields in Fazilka report water levels between 21 and 60 feet.

The shallower water tables in Fazilka contrast with the deeper tables found in other districts, emphasizing regional differences in aquifer characteristics and groundwater recharge rates. Sangrur and Hoshiarpur districts exhibit deeper water tables, with Sangrur predominantly between 141 and 180 feet and Hoshiarpur showing similar depths for about 50% of respondents. The deeper water levels in Sangrur reflect the district's heavy reliance on groundwater, exacerbated by poorly maintained canal infrastructure that fails to provide consistent surface water access. The declining water tables in Sangrur and similar districts highlight unsustainable extraction rates driven by intensive agricultural practices and ineffective surface water management. In Rupnagar, a significant proportion of respondents (69%) report water levels between 101 and 140 feet, suggesting a moderate groundwater depth compared to other districts. The relatively higher water table in Rupnagar can be partially attributed to its location and rainfall patterns, which aid groundwater recharge. Sangrur district facing severe groundwater depletion with 64.85% of bore wells extending beyond 300 feet, highlighting a considerable reliance on deeper groundwater (Table 3). This trend raises concerns about sustainable extraction rates and the potential for further depletion of the water table.

In Fazilka, nearly 49% of bore wells are less than 100 feet deep, indicating a reliance on accessible groundwater despite challenges like periodic canal water shortages and but this does not imply ample water availability. This points to the regional limitation where quality water is accessible only at certain depths, beyond which extraction becomes unfeasible. In contrast, Bathinda shows over 80% of bore wells situated between 100-200 feet, reflecting dependence on groundwater due to limited surface water during peak cropping seasons. Similarly, Hoshiarpur and Rupnagar report 40.21 and 76.44% of bore wells, respectively, in this depth category. The presence of bore wells beyond 400 feet in Sangrur (15.15%) and Bathinda (15.54%) emphasizes the risks of deep extraction on local ecosystems. Overall, the varying bore well depths across these districts reflect different groundwater management strategies, underscoring the urgent need for sustainable practices to address groundwater depletion and ensure agricultural viability in Punjab. Despite the presence of surface water, the preference for water-intensive paddy cultivation has intensified the pressure on groundwater resources, exacerbating the region's growing water crisis.

In Rupnagar district, with the highest number of electric motors (225), predominantly in the 12.5-15 hp range, farmers employ significant power to extract groundwater. In Sangrur district, the higher motor capacities (17.5-20 hp) align with the deeper water tables, reflecting the energy-intensive nature of groundwater extraction in this region. Conversely, in Fazilka and Bathinda districts, motor capacities are generally lower (5-10 hp), corresponding with the shallower water tables and partial reliance on canal water. This lower capacity highlights the supplementary role of canal water in these districts' irrigation practices.

Water footprint and water productivity of crops: There are significant variations in bore depth, water levels, and electric motor capacities across districts, reflecting differences in groundwater availability and extraction needs. Sangrur district recorded the deepest bore depth (355 ft), with a water level of about 160 ft, and the highest motor capacity (19.22 hp), indicating greater extraction challenges. The primary reason for this is the extensive area under rice cultivation and the widespread adoption of the long-duration variety PUSA 44, which has led to significant groundwater exploitation in the district (Kaur 2021). PUSA 44 requires higher water input due to its longer crop duration (Singh et al 2022). As a result, Sangrur's heavy reliance on groundwater and the cultivation of long-duration varieties also contributed to the highest water footprint for Basmati rice (3357 l/kg). In contrast, Fazilka district had the shallowest bore (94.78 ft), with a water level of about 28 ft, and the lowest motor capacity (5.53 hp).

Water footprints (WFP) also varied across crops, with Bathinda district showing the highest water footprint for both paddy (2366 l/kg) and wheat (760 l/kg), likely due to its dry conditions requiring more irrigation. The water footprint for

Table 2. Percent distribution of the respondents on the basis of water level at field in different districts

Water level (ft)	Sangrur (n=100)	Hoshiarpur (n=100)	Rupnagar (n=100)	Fazilka (n=100)	Bathinda (n=100)
0-20	-	-	-	33	24
21-60	-	30	-	63	22
61-100	-	20	31	3	45
101-140	2	-	69	1	6
141-180	98	50	-	-	3

Table 3. Percent distribution of the bore well on the basis of bore depth in different districts

Bore depth (ft)	Sangrur	Hoshiarpur	Rupnagar	Fazilka	Bathinda
<100	-	-	-	48.94	-
100-200	-	40.21	76.44	51.06	80.31
200-300	20.00	27.51	23.56	-	1.55
300-400	64.85	32.28	-	-	2.59
400-500	15.15	-	-	-	7.77
500-600	-	-	-	-	5.70
>600	-	-	-	-	2.07

Table 4. Distribution of the electric motors per 100 farmers on the basis of different capacityin different districts

Motor capacity (hp)	Sangrur	Hoshiarpur	Rupnagar	Fazilka	Bathinda
3-5	-	-	-	9	-
5-10	-	181	90	93	127
12.5-15	33	4	133	-	50
17.5-20	119	-	2	-	-
25-30	15	-	-	-	2
Total	167	185	225	102	179

*Multiple Responses

Table 5. Average groundwater extraction and water use for the cultivation of crops

Districts	Bore depth (ft)	Water level (ft)	Electric motor capacity (hp)	Water productivity (kg/m^3)			Water footprints (l/kg)		
				Paddy	Basmati	Wheat	Paddy	Basmati	Wheat
Sangrur	355.00	159.65	19.22	0.445	0.298	1.658	2245	3357	603
Hoshiarpur	248.18	103.80	9.11	0.605	_	1.603	1652	_	624
Rupnagar	187.23	112.28	10.82	0.541	0.438	1.597	1849	2282	626
Fazilka	94.78	28.29	5.53	0.487	0.435	1.377	2052	2299	726
Bathinda	206.69	58.97	9.83	0.423	0.429	1.316	2366	2329	760

paddy in Sangrur district (2245 l/kg) was nearly on par with that of Bathinda (2366 l/kg). Conversely, districts like Hoshiarpur and Rupnagar, which receive higher rainfall and have loamy soils, had lower water footprints—1652 l/kg and 1849 l/kg, respectively. Similarly, water productivity varies across districts, with higher productivity observed for paddy in Hoshiarpur (0.605 kg/m^3) and Rupnagar (0.541 kg/m^3). For wheat, water productivity was higher in Sangrur (1.658 kg/m^3), Hoshiarpur (1.603 kg/m^3), and Rupnagar (1.597 kg/m^3), due to differences in soil types and weather conditions

CONCLUSIONS

This study highlights the critical state of groundwater resources in Punjab, particularly in districts like Sangrur, where borewells extend beyond 300 feet and water levels are as deep as 180 feet, reflecting excessive reliance on deep groundwater extraction. There was significant disparities in bore depths, water levels, and motor capacities across districts, with Sangrur exhibiting the highest motor capacities (up to 19.22 hp) to meet the demands of groundwater extraction for high-water-use crops. In contrast, districts like Fazilka, with shallower water tables and lower motor capacities (5.53 hp), partially offset their irrigation needs with canal water. Water productivity and water footprint data suggest significant variation across districts, with Sangrur and Bathinda recording the highest water footprints for paddy and wheat. Rupnagar and Hoshiarpur districts, with higher rainfall and more efficient water use practices, demonstrate better water productivity. The results underline the importance of region-specific water management strategies that promote efficient irrigation and encourage crop diversification to reduce pressure on groundwater resources. Implementing improved irrigation practices, optimizing water use in agriculture, and enhancing surface water management are essential steps to ensure the long-term sustainability of Punjab's water resources and agricultural viability.

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Effect of Sewage Sludge Application on Growth Parameters and Uptake of Micronutrients by Poplar Nursery

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Abstract: Field study was conducted to study the effect of different doses of sewage sludge and its combination with chemical fertilizers on growth parameters and uptake of micronutrients by poplar nursery. Sixteen treatments were applied namely control, 50% RDF (recommended dose of fertilizers), 75% RDF, 100% RDF, 5 t/ha SS (sewage sludge), 10 t/ha SS, 15 t/ha SS, 50% RDF + 5 t/ha SS, 50% RDF + 10 t/ha SS, 50% RDF + 15 t/ha SS, 75% RDF + 5 t/ha SS, 75% RDF + 10 t/ha SS, 75% RDF + 15 t/ha SS, 100% RDF + 5 t/ha SS, 100% RDF + 10 t/ha SS and 100% RDF + 15 t/ha SS. The treatments were applied in randomized block design in three replications in the field having loamy sand soil texture. The growth parameters (height and collar diameter) differed significantly among various treatments. Concentration and uptake of micronutrients (Fe, Mn, Cu, Zn and Ni) by poplar nursery were analysed. In comparison to other treatments, concentration and uptake of micronutrients were significantly higher at 50% RDF + 15 t/ha SS and 75% RDF + 10 t/ha SS. Litterfall had the highest concentration of nutrients, followed by roots and shoots. The soil's micronutrient build-up peaked at 100% RDF + 15 t/ha SS. It is advised to use either 50% RDF + 15 t/ha SS or 75% RDF + 10 t/ha SS to ensure healthy poplar nursery growth and for saving of inorganic fertilizers.

Keywords: Micronutrients, Litterfall, Nutrient uptake, Sewage sludge

Pollution is a significant challenge for developing and underdeveloped countries, primarily due to increased urbanization and industrialization, along with the global issue of unsustainable population growth. This has led to the generation of large amounts of various types of solid waste, including sewage sludge (Singh et al 2015). Approximately three billion people living in urban areas around the world produce about 1.2 kg of solid waste per person each day. By 2025, it is projected that the urban population will grow to 4.3 billion, generating roughly 1.42 kg of solid waste per person daily (Hossain et al 2017). In India, major cities alone are reported to generate about 38,354 million liters of sewage daily, while the sewage treatment infrastructure can only process 11,786 million liters per day (Kaur et al 2012). On the other hand, excessive use of chemical fertilizers deteriorate the soil quality and contaminate groundwater and other water bodies through leaching and runoff losses. Therefore, a reliable source is required for fertilization. Hence, the use of sewage sludge can be considered as one of the reliable options for fertilization in agriculture to overcome these issues.

Sewage sludge is semi-solid residual material produced from the treatment of municipal or industrial wastewater. When sewage sludge is recycled through sludge treatment it is frequently referred as "biosolids". Biosolids are organic wastewater sediments that can be recycled after stabilisation processes such as anaerobic digestion and composting. The amount of wastewater treated and the treatment method employed have an impact on the amount of sewage sludge produced. It contains 50-70% organic matter and 30-50% inorganic material, as well as diversity of microorganisms (Gul et al 2015, Raheem et al 2018). It contains a considerable amount of micronutrients which promotes the plant growth (Fytili and Zabaniotou 2008, Tyagi and Lo 2013, Samolada and Zabaniotou 2014).

Various methods have been developed to safely dispose sewage waste; the most common are application to soil, sea dumping and landfilling (Gude 2015, Zhang et al 2017). Most of the cities and towns along the riverbank dumped waste into the waterways. Many nations have implemented environment legislation that forbids the discharge of sewage and effluents into rivers (Singh and Agrawal 2008), which has led to the accumulation of larger volumes of sewage sludge than before. On the other hand, disposing of sewage sludge in landfills is associated with leachate issues and higher CO_2 emission into the environment (Barberio et al 2013). Land application is therefore among the best methods of disposing of sewage sludge. Efficient nutrient recycling is key requirement of sustainable agriculture over long term. By applying sewage sludge as soil amendments in arable fields, these nutrients can be recycled (Kirchmann et al 2017). Khanna (2019) suggested that sewage sludge can be regenerated by employing it as organic manure in agriculture. At present, there is a lot of interest in the use of sewage sludge for reclamation and soil amendment. Sludge use on agricultural land can improve the soil's physical, chemical, and biological properties (Singh and Agrawal 2008). About half of the solid sewage sludge is composed of organic matter, which is known to enhance the physical characteristics of soil, such as bulk density and water-holding capacity, as well as to form stable complexes of heavy organic metals and reduce the amount of heavy metals present in contaminated soil (Kominko et al 2017). Sludge application improves the physical and chemical characteristics of the soil and has a major favourable impact on plant growth which increases the nutritional value of crop plant (Singh and Agrawal 2008, Eid et al 2019, Guoqing et al 2019).

Application of sewage sludge in forestry is considered as more reliable and safest option of disposing of sewage sludge as forest products are not consumed directly. This practice will also not affect the quality of soil as trees are long lived and store trace elements in their aerial parts. Poplar (*Populus deltoides* Bartr.) is a quick growing tree with a wide range of hybrids and cultivars. It is well known for their ability to exhibit phytoremediation (Guoqing et al 2019). It is an economical way to handle solid waste. Trees are important for environmental purification because they detoxify soil by absorbing large amounts of toxic metals (Madiwalar et al 2023, Singh et al 2020). Absolutely, the use of sewage sludge in growing poplar seedlings presents a promising yet underexplored area. Poplar trees are favoured for their fast growth and adaptability, which makes them ideal for various applications, including biomass production and environmental remediation.

MATERIAL AND METHODS

Study area: The research was conducted in the Forestry Research Area at Punjab Agricultural University, Ludhiana in the year 2022-2023. Ludhiana is situated at 244 meters above sea level, at a latitude of 30° 56' North and a longitude of 75° 52' East. The area's climate ranges from subtropical to tropical. The average annual maximum temperature is 29.8°C, while the average minimum temperature is 16.8°C. The region receives about 760 mm of rainfall each year.

Experimental details: Sewage sludge was applied in poplar nursery under field conditions having loamy sand soil texture replicated thrice in randomized block design in February 2022. Sixteen treatments were applied consisting of different rates of chemical fertilizer and sewage sludge. These were control (T1), 50% RDF (recommended dose of fertilizers) (T2), 75% RDF (T3), 100% RDF (T4), 5 t/ha SS (T5), 10 t/ha SS (T6), 15 t/ha SS (T7), 50% RDF + 5 t/ha SS (T8), 50% RDF + 10 t/ha SS (T9), 50% RDF + 15 t/ha SS (T10), 75% RDF + 5 t/ha SS (T11), 75% RDF + 10 t/ha SS (T12), 75% RDF + 15 t/ha SS (T13), 100% RDF + 5 t/ha SS (T14), 100% RDF + 10 t/ha SS (T15) and 100% RDF + 15 t/ha SS (T16). The recommended dose of N, P_2O_5 and K_2O was 125, 150 and 75 kg/ha, respectively. Application of full dose of phosphorus, potassium and sewage sludge was done at planting. Application of nitrogen was done in two splits, one half in first week of July and remaining in first week of August. The plants were uprooted after one year of nursery growth in January 2023. Different plant parts (shoot and root) were separated and litterfall was collected separately from each plot.

Observations: The plant height was recorded in January 2023 using a measuring scale from base to apex of the shoots in centimetres. The collar diameter of plants was measured using digital calliper in millimetres. The concentration and uptake of micronutrients (Fe, Mn, Cu, Zn and Ni) by shoot, root and litterfall was determined. Standard analytical techniques were used to ascertain the physico-chemical characteristics of the experimental soil and sewage sludge (Table 1). Experimental soil had an alkaline pH and deficit in organic carbon and available nitrogen. Available phosphorus content was in medium range and available potassium and micronutrients were in sufficient range. Sewage sludge was rich in organic carbon content (32.9%) while Ni content was lowest (43.9 mg kg^{-1}) among different elements.

Plant and sewage sludge analysis: After harvesting of poplar nursery in January 2023, shoot, root and litterfall samples were collected from different plots and fresh weight was recorded after removing dust from samples. Then, they were oven dried at 65 ±2˚C until the constant weight was attained. Samples were stored in paper bags after proper

Table 1. Physico-chemical properties and nutrient status of the experimental soil and sewage sludge used in the study

Property	Soil	Property	Sewage sludge
Sand (%)	80.9	Organic carbon (%)	32.9
Silt (%)	10.5	Total nitrogen (%)	1.9
Clay (%)	8.6	Total phosphorus (%)	0.18
Soil texture	Loamy sand	Total potassium (%)	0.31
$pH_{1:2}$	8.48	Fe (mg/kg)	8457
EC (dS/m)	0.22	Mn (mg/kg)	223.8
Organic carbon (%)	0.35	Cu (mg/kg)	86.1
Fe (mg/kg)	3.80	Zn (mg/kg)	364.3
Mn (mg/kg)	1.27	Ni (mg/kg)	43.9
Cu (mg/k)	0.52		
Zn (mg/kg)	1.40		
Ni (mg/kg)	0.179		

grinding for further analysis. For organic carbon analysis of sewage sludge, it was heated in muffle furnace at a temperature of 550 ˚C for one hour and organic matter content was determined by difference in weight of sewage sludge before and after heating. Nitrogen analysis in sewage sludge was done using Kjeldahl method given by Jackson (1973), in which one gram of sewage sludge was digested with 10 g of catalyst mixture (20 g of $CuSO_4.6H_2O$, 1 g Se-powder and 3 g HgO with 480 g of potassium sulphate). P and K content in sewage sludge and micronutrients (Fe, Mn, Cu, Zn and Ni) in plants and sewage sludge were determined by digesting one gram sample of sewage sludge with 10-15 ml of diacid mixture (HNO_3 and $HClO_4$ in 3:1 ratio). After making the volume of digested extract with distilled water, readings were taken on inductively Coupled Plasma-Optical Emission Spectrometer (ICP-OES). The uptake of micronutrients by shoot, root and litterfall was determined by multiplying the concentration of nutrients with their dry biomass.

Soil sampling and analysis: Before initiating the experiment, a composite soil sample was collected from surface layer (0-15 cm) for basic physico-chemical properties of experimental soil. After the completion of experiment, post-harvest soil samples were collected from all replication of different treatments. Before chemical analysis, samples were properly air dried and grinded and then sieved through 2 mm sieve. International pipette method was adopted to determine the texture of soil. Soil pH and electrical conductivity was determined by method employed by Jackson (1973) using soil:water ratio of 1:2. Wet digestion method (Jackson 1973) was followed to assess the organic carbon content of soil. Build-up of micronutrients in soil after application of different doses of chemical fertilizer and sewage sludge was done using DTPA extractable method (Lindsay and Norvell 1978).

Statistical analysis: The data were analysed in randomized block design using CPCS-1 software.

RESULTS AND DISCUSSION

Growth parameters: The plant height and collar diameter of one year old poplar nursery were maximum (409.1 cm and 27.88 mm, respectively) when treated with 100% RDF + 10 t/ha SS (T15) which were statistically similar with T10, T12, T13 and T16. The treatments where there was no application of chemical fertilizers and sewage sludge showed the lower plant height and collar diameter (277.9 cm and 17.31 mm, respectively) as compared to other treatments. Maximum increment was observed where combination of chemical fertilizers and sewage sludge was applied which might be due to the better utilization and more availability of nutrients for plant growth (Jamil and Bayan 2004).

Concentration and uptake of micronutrients by shoot: The concentration and uptake of micronutrients by shoot showed significant increment when applied with sewage sludge and its combination with chemical fertilizer over control (Table 2, 3). Maximum content and uptake of micronutrients was recorded when combined doses of sewage sludge and chemical fertilizer were applied. Fe, Zn and Ni showed highest content (197.3, 19.34 and 0.877 mg/kg, respectively) in shoots when applied with 100% RDF + 15 t/ha SS which was statistically similar with different doses of sewage sludge except 5 t/ha SS, 50% RDF + 15 t/ha SS and 75% RDF + 10 t/ha SS. Mn showed the highest concentration (27.16 mg/kg) at 50% recommended dose of fertilizer + 15 t/ha of sewage sludge whereas its uptake was highest (460.4 g/ha) at 100% RDF + 10 t/ha SS which was at par with 50% RDF + 15 t/ha SS. The maximum (3727 g/ha and 16.35 g/ha, respectively) uptake of Fe and Ni was also at 100% RDF + 10 t/ha SS which was statistically similar with 75% RDF + 15 t/ha SS. The Zn showed highest uptake (356.24 g/ha) at 100% RDF + 15 t/ha SS which was statistically similar with 75% RDF + 15 t/ha SS. The uptake of micronutrients improved as the dose of sewage sludge increased compared to the control. The combined use of chemical fertilizers and sewage sludge significantly enhanced micronutrients uptake. Roy et al (2013) observed that integrating sewage sludge with synthetic fertilizers increased micronutrient uptake in *Spinacia oleracea*.

Concentration and uptake of micronutrients by roots: The significant increase in the concentrations of Fe, Mn, Cu, Zn and Ni in the roots was observed when sewage sludge was applied, either alone or in combination with chemical fertilizer, compared to the control. The concentration of iron in the roots notably increased with higher doses of sewage sludge. The highest levels of iron, copper, zinc and nickel were recorded at 100% RDF +15 t/ha SS (428.3, 13.74, 23.34 and 1.62 mg/kg, respectively), which were still well below toxic levels (Table 2). Manganese concentration peaked at 22.05 mg/kg with 15 t/ha of sewage sludge, which was comparable to the concentration found with 50% RDF + 15 t/ha SS. The uptake of micronutrients (Fe, Mn, Cu, Zn and

Table 2. Concentration range of micronutrients in shoot, root and litterfall under different treatments

Micronutrients (mg/kg)	Shoot	Root	Litterfall
Fe	158.7-197.3	256.3-428.3	814-1461
Mn	21.79-27.16	17.81-22.05	152.1-193
Cu	3.23-12.61	9.17-13.74	12.22-17.49
Zn	8.95-19.34	15.57-23.34	65.45-116
Ni	0.527-0.877	0.74-1.62	3.27-5.04

Ni) by roots significantly increased compared to the control when different doses of sewage sludge were applied (Table 4). The highest micronutrient uptake was recorded with the combination of sewage sludge and chemical fertilizer. The greatest uptake of Fe and Ni (1386.9 and 5.20 g/ha, respectively) occurred with 100% RDF + 10 t/ha SS, which was similar to the uptake observed with 75% RDF + 15 t/ha SS. For Mn and Zn, the highest uptake (74.33 and 75.19 g/ha, respectively) was achieved with 75% RDF + 15 t/ha SS. The uptake of iron by poplar roots increased with the

Table 3. Uptake of micronutrients by shoot after application of different levels of chemical fertilizer and sewage sludge

Treatments	Iron (g/ha)	Manganese (g/ha)	Copper (g/ha)	Zinc (g/ha)	Nickel (g/ha)
T1 (control)	1485	203.2	30.33	84.14	4.95
T2 (50 % RDF)	1541	217.1	27.65	87.79	5.24
T3 (75% RDF)	1618	230.1	42.15	103.27	5.70
T4 (100% RDF)	2267	367.3	54.38	170.55	7.49
T5 (5 t/ha SS)	2407	306.6	73.30	152.78	8.90
T6 (10 t/ha SS)	2567	332.8	71.30	173.21	9.87
T7 (15 t/ha SS)	2847	398.5	90.35	253.32	10.74
T8 (50% RDF + 5 t/ha SS)	2455	320.5	78.95	197.25	10.10
T9 (50% RDF + 10 t/ha SS)	2666	335.2	85.63	219.46	10.25
T10 (50% RDF + 15 t/ha SS)	2954	431.5	109.21	273.07	11.87
T11 (75% RDF + 5 t/ha SS)	2503	303.8	70.09	184.04	10.12
T12 (75% RDF + 10 t/ha SS)	3229	336.6	85.96	289.67	12.91
T13 (75% RDF + 15 t/ha SS)	3538	373.1	97.89	310.14	14.46
T14 (100% RDF + 5 t/ha SS)	2668	290.5	149.95	187.07	11.37
T15 (100% RDF +10 t/ha SS)	3727	460.4	241.68	335.55	16.35
T16 (100% RDF + 15 t/ha SS)	3627	409.5	232.13	356.24	16.16
CD (p=0.05)	583.8	67.34	25.84	56.84	2.30

Table 4. Uptake of micronutrients by roots after application of different levels of chemical fertilizer and sewage sludge

Treatments*	Iron (g/ha)	Manganese (g/ha)	Copper (g/ha)	Zinc (g/ha)	Nickel (g/ha)
T1	665.0	45.92	23.67	40.35	1.92
T2	722.8	53.67	24.55	42.96	2.59
T3	810.8	56.65	26.64	47.45	2.69
T4	759.7	60.63	31.62	52.82	3.14
T5	966.8	56.56	31.24	60.51	3.58
T6	1070.5	63.35	33.72	66.37	3.64
T7	1074.0	67.14	34.92	67.95	3.78
T8	933.8	58.51	33.75	59.81	3.96
T9	1137.9	59.48	39.66	70.13	4.37
T10	1196.8	69.40	41.56	71.09	4.66
T11	1038.5	56.16	35.65	63.04	3.99
T12	1150.2	62.35	38.86	66.05	4.66
T13	1221.6	74.33	41.36	75.19	4.77
T14	1120.9	61.82	35.09	62.24	4.44
T15	1386.9	66.70	41.33	72.46	5.20
T16	1374.5	69.76	44.02	74.89	5.20
CD (p=0.05)	184.9	10.89	4.60	10.66	0.71

*See Table 3 for details

application of chemical fertilizer, sewage sludge, or a combination of both, compared to the control. The boost in iron uptake with sewage sludge application is attributed to the micronutrients provided by the sludge. Additionally, the addition of sewage sludge lowered soil pH, enhancing the availability of micronutrients in the soil, which further increased iron uptake (Sridhar 2002). The combination of sewage sludge and chemical fertilizer also improved iron uptake by poplar roots, likely due to the greater availability of micronutrients in the root zone. These findings are consistent with the study by Sreeramulu (2001).

Concentration and uptake of micronutrients by litterfall: The concentrations of Fe and Mn rose with increasing doses of sewage sludge. The highest levels of Fe, Cu, Zn and Ni (1461, 17.49, 116 and 5.04 mg/kg, respectively) were recorded at 100% RDF + 15 t/ha SS (Table 2). Meanwhile, the peak accumulation of Mn (193 mg/kg) was observed at 15 t/ha of sewage sludge, which was statistically similar to the levels found with 50% RDF + 15 t/ha SS. Applying sewage sludge alone or in combination with chemical fertilizer significantly increased the uptake of micronutrients (Fe, Mn, Cu, Zn and Ni) by litterfall compared to the control. The uptake of micronutrients, except Ni, increased notably with higher doses of sewage sludge (Table 5). The highest Mn uptake by litterfall (227.3 g/ha) occurred with 50% RDF + 15 t/ha SS, while the greatest uptake of Cu and Ni (19.98 and 5.76 g/ha, respectively) was observed with 100% RDF + 15 t/ha SS. This level of Cu and Ni uptake was similar to that achieved with 50 or 75% of the recommended fertilizer dose combined with 15 t/ha of sewage sludge. When litterfall is returned to the soil, the nutrients it contains are released back into the soil as it decomposes. Numerous studies have noted significant enhancements in soil nutrient levels as a result of adding litterfall and the subsequent nutrient release during its decomposition (Sharma et al 2015, Singh et al 2021).

Build-up of micronutrients in soil: Applying sewage sludge at various rates significantly enhanced the accumulation of micronutrients in the soil compared to the control (Table 6). The highest levels of Fe, Mn and Ni were achieved with 100% of the recommended fertilizer dose combined with 15 t/ha of sewage sludge, while the greatest accumulation of Zn was observed with 100% of the recommended fertilizer dose plus 10 t/ha of sewage sludge. The addition of sewage sludge to the soil resulted in an increased accumulation of micronutrients. This is because sewage sludge lowers soil pH, which enhances the availability of micronutrients by dissolving metals associated with organic matter (Singh and Sharma 2007, Delibacak et al 2009). Additionally, sewage sludge provides a substantial amount of micronutrients to the soil. The micronutrient content in the soil also rose with the application of both chemical fertilizer and sewage sludge, likely due to the

Table 5. Uptake of micronutrients by litterfall after application of different levels of chemical fertilizer and sewage sludge

Treatments*	Iron (g/ha)	Manganese (g/ha)	Copper (g/ha)	Zinc (g/ha)	Nickel (g/ha)
T1	754.5	141.1	11.36	60.82	3.03
T2	947.0	154.2	12.95	69.26	3.43
T3	1025.1	172.0	13.24	76.40	3.86
T4	1006.6	180.2	14.06	76.50	3.85
T5	1128.4	177.0	14.94	78.71	4.16
T6	1306.4	201.7	17.17	85.71	4.71
T7	1352.3	213.1	18.52	92.02	4.90
T8	1245.3	189.7	15.78	82.15	4.40
T9	1412.2	217.9	18.96	94.02	5.33
T10	1508.3	227.3	19.58	102.9	5.65
T11	1251.2	183.9	15.56	80.1	4.48
T12	1454.4	212.3	16.29	90.2	4.88
T13	1409.5	214.3	17.39	96.6	5.20
T14	1499.3	198.3	16.37	103.1	5.38
T15	1537.7	204.2	17.63	116.7	5.46
T16	1668.6	213.3	19.98	132.4	5.76
CD (p=0.05)	79.7	13.11	2.85	9.5	0.85

*See Table 3 for details

Table 6. Build-up of micronutrients in soil after application of different levels of chemical fertilizer and sewage sludge

Treatments*	Iron (g/ha)	Manganese (g/ha)	Copper (g/ha)	Zinc (g/ha)	Nickel (g/ha)
T1	4.51	6.63	0.387	1.361	0.154
T2	4.63	6.60	0.388	1.367	0.159
T3	6.01	7.99	0.395	1.413	0.161
T4	5.81	7.92	0.384	1.410	0.164
T5	5.20	7.22	0.559	1.610	0.172
T6	5.30	8.26	0.599	1.670	0.174
T7	5.66	9.42	0.656	1.760	0.176
T8	5.57	7.57	0.609	1.695	0.201
T9	5.89	8.57	0.635	1.774	0.222
T10	6.50	9.99	0.673	1.780	0.223
T11	6.62	7.82	0.587	1.892	0.224
T12	7.08	8.85	0.590	2.018	0.227
T13	7.22	10.02	0.679	2.086	0.233
T14	6.84	8.05	0.612	2.133	0.239
T15	7.17	9.94	0.626	2.263	0.242
T16	7.38	10.10	0.631	2.184	0.303
CD (p=0.05)	1.37	1.13	0.128	0.284	0.032

*See Table 3 for details

increased availability of micronutrients. These findings are consistent with those reported by Sridhar et al (2002).

CONCLUSIONS

Sewage waste, which is rich in organic matter and essential nutrients needed for plant growth, can be utilized as manure. In this study, applying various doses of sewage sludge significantly enhanced growth parameters such as plant height and collar diameter as well as plant biomass. The highest plant height and collar diameter were achieved with 100% RDF + 10 t/ha SS, which was comparable to the results from 50% RDF + 15 t/ha SS and 75% RDF + 10 t/ha SS. The dry biomass of shoots, roots, and litterfall increased notably with sewage sludge treatment compared to no sewage sludge or chemical fertilizer application. Additionally, varying rates of sewage sludge and chemical fertilizers significantly boosted the concentration and uptake of micronutrients (Fe, Mn, Cu, Zn and Ni) in shoots, roots and litterfall compared to the control.

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Performance of Wheat with Deficit and Full Sub-Surface Drip Irrigation versus Surface Flood Irrigation

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Abstract: Subsurface drip irrigation (SDI) is an emerging micro-irrigation technique, particularly promising for close-spaced crops like wheat. SDI minimizes evaporation losses by delivering water directly to the root zone, potentially enhancing yield with reduced water consumption. This field study, conducted at Punjab Agricultural University's Regional Research Stations in Abohar and Faridkot, investigated fertigation scheduling and wheat performance under deficit SDI regimes. Treatments included three SDI levels (60, 80, and 100% of crop evapotranspiration, ETc) combined with two fertigation levels (60 and 80% of the recommended nitrogen dose, RDN), alongside a surface flood irrigation control (100% RDN). SDI at 80 and 100% ETc significantly increased grain yield by 9.3 and 12.1%, respectively, compared to the control, with corresponding increases of 10.1 and 12.9% over 60% ETc. Both fertigation levels yielded higher grain yields (5.5-8.3% increase over control), but no significant difference was observed between them. SDI improved nitrogen use efficiency (NUE), peaking at 80% and 100% ETc. Water savings with SDI ranged from 54.5-66.0% in Abohar to 27.9-46.8% in Faridkot, compared to the control. The 60% ETc treatment, with the least water application, achieved the highest apparent water productivity (AWP), followed by 80% and 100% ETc under SDI. Surface flood irrigation resulted in the lowest AWP due to lower yield and higher water use. This study indicates that SDI at 80% ETc, coupled with fertigation at 60% RDN, optimizes wheat yield and AWP.

Keywords: Wheat, Drip irrigation, Fertigation, Grain yield, Irrigation water applied, Nitrogen use efficiency

Wheat (*Triticum aestivum* L.), a staple food worldwide, holds particular significance in India, where it ranks as the primary cereal crop. The nation leads globally in wheat acreage, spanning 30.79 million hectares, and stands second only to China in production, with 98.51 million tonnes. In Punjab, wheat dominates the winter cropping season, covering 3.53 million hectares and yielding 17.19 million tonnes (Anonymous 2022).

Despite its importance, wheat cultivation in Punjab, like many field crops, heavily relies on surface flood irrigation. This method, while prevalent due to historically accessible canal water and subsidized electricity for tubewells, leads to substantial water wastage (Singh and Singh 2013). The unsustainable nature of flood irrigation necessitates its replacement with more efficient systems to conserve this precious resource (Singh et al. 2018).The global freshwater supply faces increasing strain from a burgeoning population and the agricultural sector's substantial water demand (Gleick and Palaniappan 2010, Hoekstra and Mekonnen 2012). In Punjab, over-extraction of groundwater has resulted in a concerning decline in aquifer levels, with 80% of the area experiencing depletion at a rate of 0.4 meters per year (Brar et al 2012). Addressing this critical issue demands innovative irrigation strategies that reduce water use without compromising crop yield.

Subsurface drip irrigation (SDI), traditionally employed for high-value, widely spaced crops, offers a potential solution for field crops like wheat. In SDI, drip lines are buried near the root zone, minimizing evaporation, facilitating field operations, and optimizing nutrient uptake while reducing weed growth and labor costs (Camp 2018). Research suggests SDI promotes deeper root development and improves water use efficiency compared to surface drip irrigation (Patra et al 2023, Yang et al 2019). This field study aimed to evaluate SDI's potential for wheat cultivation in Punjab, specifically focusing on optimizing irrigation scheduling under SDI in a wheat-cotton rotation system.

MATERIAL AND METHODS

Site description: Field experiments were conducted during the 2019-2020 winter season at two research stations of Punjab Agricultural University: Regional Research Station in Abohar (30.80°N, 74.12°E) and the Regional Research Station in Faridkot (30.40°N, 74.44°E). This southwestern region of Punjab is characterized by a predominantly cotton-wheat cropping rotation. The mean maximum and minimum temperatures during the experimental period were 23.2°C and 9.6°C in Abohar, and 22.9°C and 12.8°C in Faridkot, respectively (Table 1). The soil texture was loamy sand in Abohar and sandy loam in Faridkot. Soil moisture holding capacity and bulk density for each location are presented in Tables 2 and 3.

Drip layout: In the summer of 2018, prior to cotton sowing, drip laterals were installed 20 cm beneath the soil surface at both locations using a tractor-mounted lateral laying machine. The laterals were spaced 67.5 cm apart and equipped with in-line drippers spaced 20 cm apart, each with a discharge rate of 2.2 liters per hour. Both cotton and wheat crops were sown parallel to the subsurface drip laterals. This arrangement allowed each lateral to serve one row of cotton (67.5 cm row spacing) in the summer and three rows of wheat (22.5 cm row spacing) in the winter.

Field preparation and crop management: The pre-sowing flood irrigation was applied to ensure adequate moisture for wheat germination. Following cotton harvest, the field was prepared with a single pass of a tractor-operated rotavator and one pass with a planker to create a firm seedbed. Wheat was sown on November 6, 2019, in Faridkot and November 11, 2019, in Abohar, with a row spacing of 22.5 cm. Each treatment plot had a gross size of 12 rows x 18 m. Standard agronomic practices, except for irrigation and nitrogen management, were followed as per Punjab Agricultural University recommendations for wheat (Anonymous 2022). The crop was harvested on April 15, 2020, in Abohar and April 23, 2020, in Faridkot.

Experimental treatments and design: The experiment followed a randomized complete block design with three replications. Treatments consisted of combinations of three subsurface drip irrigation regimes (60, 80% and 100% ETc) and two nitrogen fertigation levels (60 and 80% RDN). These six SDI treatments were compared to a control treatment of flood irrigation with 100% RDN.

Irrigation/Fertigation Scheduling

Control: The first flood irrigation was applied 25 days after sowing, with subsequent irrigations at 3-4 week intervals, depending on rainfall. The final irrigation was applied in the last week of March at both locations. The recommended nitrogen dose of 125 kg N/ha was applied as urea in two equal splits: the first at the first irrigation and the second after the second irrigation.

SDI: The first irrigation was applied 21 days after sowing. Subsequent irrigations were applied every 5 days, with varying water amounts based on the three irrigation regimes and the reference crop evapotranspiration (ETc) calculated using the FAO Penman-Monteith equation for each 5-day period. Irrigation duration was calculated considering emitter discharge rate and the number of emitters per plot using the following formula:

$$\text{Time (minutes)} = \frac{\text{Amount of water required (mm) x Plot area (sq.m.)x 60}}{\text{Discharge rate of emitter (litres/hour) x Number of emitters in plot}}$$

Table 2. Moisture retention capacity of soil at experimental fields

Soil depth (cm)	Moisture content (%) at field capacity		Moisture content (%) at permanent wilting point (PWP)	
	Faridkot	Abohar	Faridkot	Abohar
0-15	21.0	19.8	12.5	8.9
15-30	16.7	14.3	10.1	10.3
30-45	16.0	15.0	9.9	10.0
45-60	18.2	16.4	10.9	10.1
60-90	17.6	16.6	10.1	8.2
90-120	16.2	15.0	9.9	9.1
120-150	18.3	16.7	12.1	10.7

Table 3. Bulk density of soil at experimental fields

Soil depth (cm)	Bulk density (g cm^{-3})	
	Faridkot	Abohar
0-15	1.55	1.59
15-30	1.53	1.69
30-60	1.67	1.71

Table 1. Mean monthly meteorological data of experimental sites during crop season

Month	Abohar				Faridkot			
	Temperature (°C)		Total rainfall (mm)	Rainy days (no.)	Temperature (°C)		Total rainfall (mm)	Rainy days (no.)
	Maximum	Minimum			Maximum	Minimum		
November	25.6	12.6	33.8	4	25.2	12.1	26.8	4
December	16.6	5.4	22.4	1	15.6	5.9	15.3	2
January	16.3	5.2	39.2	3	15.8	5.5	38.6	3
February	22.6	7.4	1.8	0	22.3	8.2	1.2	1
March	24.8	12.4	80.4	7	24.7	12.9	57.2	5
April	33.2	16.8	8.4	4	33.6	18.1	7.0	3

Nitrogen fertigation under SDI was applied in five splits, with the first dose at the first irrigation and the remaining four doses applied with every alternate irrigation, according to the treatment.

Data recording: Grain yield was recorded from the net plot area (2.25 m x 18 m) after manual harvesting and threshing and converted to kg/ha. Nitrogen use efficiency (NUE) was calculated by dividing grain yield (kg/ha) by nitrogen uptake (kg/ha). Apparent water productivity (AWP) was calculated as:

$$\text{AWP (kg m}^{-3}\text{)} = \frac{\text{Grain yield (kg ha}^{-1}\text{)}}{\text{Irrigation water applied (mm) x 10}}$$

Statistical analysis: Data were analyzed using ANOVA (GLM procedure in SAS 9.3), and means were separated using LSD at $p < 0.05$.

RESULTS AND DISCUSSION

Grain yield: Subsurface drip irrigation (SDI) consistently improved grain yield compared to surface flood irrigation (control) at both experimental sites (Table 4). In Abohar, the yield under surface flood (3644 kg/ha) was lower than even the 60% ETc SDI treatment (4100 kg/ha). Although SDI treatments did not show statistically significant yield differences at this location, the overall yield increase compared to flood irrigation can be attributed to the precise water delivery near the root zone, minimizing evaporative losses. This efficient water use likely enabled the 60% ETc treatment to achieve yields comparable to higher SDI levels.In Faridkot, the 100% ETc SDI treatment produced the highest yield (6319 kg/ha), statistically similar to the 80% ETc treatment (6205 kg/ha). The deficit irrigation treatment (60% ETc) resulted in a lower yield than the control, possibly due to insufficient water application. Compared to 60% ETc, the 100% and 80% ETc treatments increased yield by 15.0 and 15.8% in Faridkot, and 6.0 and 2.4% in Abohar, respectively. Sinha et al (2017) also reported higher yields with SDI and fertigation compared to the control, except for SDI at 60 and 80% ETc with 60% RDN.Pooled data analysis confirmed that 100 and 80% ETc SDI treatments significantly outperformed 60% ETc, with the latter being comparable to flood irrigation. The 100 and 80% ETc SDI treatments yielded 12.1 and 9.3% more grain than the control, respectively. This yield advantage can be attributed to improved crop growth due to consistent soil moisture and nutrient availability under SDI, leading to enhanced yield components. Rao et al (2016) similarly observed comparable seed cotton yields at 100 and 80% ETc SDI, both superior to 60% ETc. The interaction between irrigation and fertigation was non-significant, the comparison between SDI treatments and the control remained significant at both locations.

Nitrogen use efficiency (NUE): Irrigation levels influenced NUE only in Faridkot, while fertigation levels significantly impacted NUE at both locations (Table 5). In Faridkot, the highest NUE was observed at 100% ETc (89.0), statistically similar to 80% ETc (87.4) but significantly higher than 60% ETc (75.3). Regarding fertigation, 80% RDN through SDI resulted in lower NUE than 60% RDN at both sites. Pooled data analysis confirmed the significance of both irrigation and fertigation levels in influencing NUE, with trends similar to those observed in Faridkot. SDI consistently outperformed flood irrigation in terms of NUE, likely due to the targeted nitrogen application minimizing losses through leaching and volatilization. These results highlight SDI's advantage over

Table 4. Influence of different levels of fertigation and irrigation on grain yield of SSDI wheat

Treatment	Abohar				Faridkot				Pooled			
Fertigation levels	60% ETc	80% ETc	100% ETc	Mean	60% ETc	80% ETc	100% ETc	Mean	60% ETc	80% ETc	100% ETc	Mean
Grain yield (kg ha^{-1})												
60% RDN	4027	4088	4316	4144	5253	6167	6297	5907	4640	5128	5307	5025
80% RDN	4173	4316	4407	4299	5460	6243	6340	6014	4817	5280	5374	5157
Mean	4100	4202	4362		5357	6205	6319		4728	5204	5340	
	Abohar				Faridkot				Pooled			
Surface flood (Control)	3644				5880				4762			
LSD (p=0.05)												
Irrigation				NS				534				282
Fertigation				NS				NS				NS
Irrigation X Fertigation				NS				NS				NS
Irrigation X Fertigation v/s Control				284				577				305

flood irrigation in improving nutrient use efficiency, consistent with findings by Bharat et al. (2015) and Singh et al (2018). The 60% RDN fertigation level under SDI demonstrated significantly higher NUE than the control, further supported by pooled data analysis. This suggests that lower nitrogen application rates can lead to improved NUE, as also reported by Jayakumar et al (2015).

Apparent water productivity (AWP): AWP, representing grain yield per unit of irrigation water applied, was significantly influenced by irrigation levels (Table 6). At both locations, the highest AWP was achieved with 60% ETc SDI (2.68 and 3.35 kg/m³ in Abohar and Faridkot, respectively), followed by 80 and 100% ETc. In Abohar, 60% ETc was significantly superior to the other SDI levels, while in Faridkot, 60 and 80% ETc were statistically similar but higher than 100% ETc. Pooled analysis confirmed these trends, with the highest AWP at 60% ETc and the lowest at 100% ETc. Fertigation levels did not significantly affect AWP, nor did the interaction between irrigation and fertigation. However, all SDI treatments significantly outperformed flood irrigation, which had the lowest AWP at both locations (0.81 kg/m³ in Abohar and 1.96 kg/m³ in Faridkot). Although non-significant, 80% RDN fertigation tended to produce higher AWP than 60% RDN, suggesting a potential benefit of slightly higher nitrogen application.

The superior AWP at 60% ETc, despite lower yield, highlights the efficient water use under deficit irrigation. In contrast, flood irrigation's high water application did not

Table 5. Influence of different levels of fertigation and irrigation on nitrogen use efficiency (NUE) of SSDI wheat

Treatment	Abohar				Faridkot				Pooled			
Fertigation levels	60% ETc	80% ETc	100% ETc	Mean	60% ETc	80% ETc	100% ETc	Mean	60% ETc	80% ETc	100% ETc	Mean
Nitrogen use efficiency (NUE)												
60% RDN	53.1	53.9	56.9	54.6	84.6	99.3	101.4	95.1	68.9	76.6	79.2	74.9
80% RDN	41.2	42.6	43.6	42.5	65.9	75.4	76.6	72.6	53.6	59.0	60.1	57.6
Mean	47.2	48.3	50.3		75.3	87.4	89.0		61.2	67.8	69.9	
	Abohar				Faridkot				Pooled			
Surface flood (Control)	26.8				56.8				42.8			
LSD (p=0.05)												
Irrigation	NS				6.8				3.5			
Fertigation	2.4				5.6				2.8			
Irrigation X Fertigation	NS				NS				NS			
Irrigation X Fertigation v/s Control	284				7.4				3.8			

Table 6. Influence of different levels of fertigation and irrigation on apparent water productivity (kg m^{-3}) of SSDI wheat

Treatment	Abohar				Faridkot				Pooled			
Fertigation levels	60% ETc	80% ETc	100% ETc	Mean	60% ETc	80% ETc	100% ETc	Mean	60% ETc	80% ETc	100% ETc	Mean
Apparent water productivity												
60% RDN	2.64	2.29	2.11	2.34	3.29	3.28	2.91	3.16	2.96	2.78	2.51	2.75
80% RDN	2.73	2.42	2.15	2.43	3.42	3.32	2.93	3.22	3.08	2.87	2.54	2.83
Mean	2.68	2.35	2.13		3.35	3.30	2.92		3.02	2.83	2.53	
	Abohar				Faridkot				Pooled			
Surface flood (Control)	0.81				1.96				1.39			
LSD (p=0.05)												
Irrigation	0.13				0.29				0.15			
Fertigation	NS				NS				NS			
Irrigation X Fertigation	NS				NS				NS			
Irrigation X Fertigation v/s Control	0.15				0.32				0.16			

translate into a proportional yield increase, resulting in the lowest AWP. This underscores the inefficiency of flood irrigation in terms of water use. Sinha et al (2017) reported the highest AWP at 100% RDN. This discrepancy may be attributed to differences in experimental conditions, crop responses, or the specific metrics used to evaluate AWP. In their study, the higher AWP at 100% RDN was likely influenced by the increased yield, as water application remained constant across fertigation levels. However, other factors, such as crop water use efficiency and nutrient uptake, might have also played a role in determining AWP.

The study demonstrates the potential of SDI to improve wheat yield, NUE, and AWP compared to conventional flood irrigation in Punjab. The 80% ETc irrigation level, coupled with 60% RDN fertigation, appears to be a promising strategy for optimizing water and nitrogen use efficiency while maintaining satisfactory yields. Further research is warranted to refine SDI management practices and explore its applicability in diverse agro-climatic conditions.

CONCLUSIONS

The 100% ETc resulted in the highest grain yield and was statistically comparable to 80% ETc.Both of these SDI irrigation levels outperformed surface flood irrigation and the 60% ETc SDI treatment. Although fertigation levels did not significantly affect grain yield under SDI, both 60 and 80% RDN applied through SDI resulted in improved grain yield and NUE compared to the 100% RDN applied via surface flood irrigation.Apparent water productivity (AWP) was significantly higher at 60% ETc in both Abohar and Faridkot, although it was comparable to 80% ETc in Faridkot. SDI achieved substantial water savings, . Surface flood irrigation exhibited the lowest AWP.On the basis of this study recommended irrigating wheat with 80% ETc and applying 60% RDN through subsurface drip irrigation. This offers a promising strategy to enhance grain yield, AWP, and NUE, contributing to sustainable water and nutrient management practices in wheat production.

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Productivity of Different Irrigation Regimes on Leaf Characteristics and NPK Levels in Sweet Cherry under High Density Orcharding System in Kashmir, India

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Abstract: The present study was carried out on drip irrigation scheduling in sweet cherry cv. Regina in Kashmir valley where this fruit crop is exclusively being grown under the rain fed conditions. The treatment combinations I_3T_3(100 percent ETc level of irrigation applied at fruit growth stage) and I_3T_4 (100 percent ETc level of irrigation applied at fruit bud differentiation stage) significantly improved growth, yield, quality, leaf characteristics and nutrient levels in sweet cherry. Crop evapotranspiration (ETc) was minimum during winter (December-February) and maximum in summer months (June-August).The average crop water requirement in sweet cherry varied from 13.48 to 22.21 litres/tree/day. Leaf area as well as leaf chlorophyll were significantly higher in plants receiving highest irrigation level as compared to control trees. The maximum leaf N content (2.107%), P content (0.193%) and K content (1.538%) were recorded when 100 per cent ETc (I_3) level of irrigation was used, which was significantly at par with leaf N and P content of sweet cherry at 75 per cent ETc (I_2) level of irrigation. On applying the higher irrigation levels (75 and 100 %), the nutrient contents in the sweet cherry leaves were significantly higher in comparison to the lower water levels (50 and 0%).The results can be utilized to manage the water requirement of sweet cherry especially during the periods of water scarcity as it defines the appropriate amounts of water requirement at different growth stages of sweet cherry thereby help in conserving the water resources to a larger extent for their use in future.

Keywords: Crop water requirement, Evapotranspiration, Irrigation, Sweet cherry

Erratic water distribution throughout the year reduces the yield and quality of fruit crops as water isn't available during their critical stages of growth and development and becomes imperative to analyse the crop water requirement of each and every crop so that irrigation can be tailored during the most important stages of crop growth. The system of irrigation used in the orchards also plays a phenomenal role in the conservation of water and increase in yield (Kumar et al 2017). The use of micro irrigation system i.e., drip irrigation uses water very efficiently with a minimum or zero wastage, use of micro irrigation in the orchards can help the farmers to mitigate the effects of drought (Sharma and Yadav 2021). Drip irrigation ensures water use efficiency as much as 90-95% (Khadeeja and Ratansharan 2017). Sweet cherry is one of the most important fruits grown throughout the temperate region of Asia, Europe, Northern Africa, Australia and most of North America. The commercially important edible cherries are mainly obtained from *Prunus avium* (sweet cherry) and *Prunus cerasus* (sour or tart cherry). Sweet cherry (*Prunus avium* L.) belongs to the family Rosaceae and sub-family Prunoideae. Attractive colour, sweetness, sourness, firmness, wealth of antioxidants and nutrients are the main characteristics for cherry quality (Gabriele et al2013). However, a very high percentage of perennial fruit orchards including the sweet cherry in India and particularly in Jammu and Kashmir are bereft of any irrigation facilities and rainfall is the only source of moisture. Consequently water is not available to the plants during their critical stages of growth, leading to poor yield and poor fruit quality. Moreover, orchards are mostly raised on foothills or *Karewas* where there are negligible irrigation facilities. The tree after harvest should be also irrigated as the stress is one of the reasons for gummosis of tree trunk. Furthermore, the traditional irrigation system of flooding practiced by a majority of orchardists results in wastage of water besides ill effect on tree growth and fruit quality. Thus, there was a need to assess the critical stages of irrigation for qualitative and quantitative attributes of cherry. Therefore, fundamental research on the water needs of the sweet cherry was undertaken so that the growers could manage their orchards properly, particularly in drought periods.

MATERIAL AND METHODS

The research was carried out at SKUAST-K, Shalimar during 2016-17 and 2017-18. The effect of four different irrigation regimes through drip irrigation system at four growth stages was tested on 4 year old sweet cherry trees cv. Regina on Gisela 5 rootstock planted at a distance of 4 x 2 m^2 spacing with uniform size, vigour and health (Table 1). Irrigation scheduling of sweet cherry trees planted under the high density orcharding system was carried out in Kashmir to meet growing water issues by evaluating the water requirement of sweet cherry on daily basis. Sweet cherry growing season was split into four phenological stages viz., fruit set stage (T_1), pit hardening stage (T_2), fruit growth stage (T_3) and fruit bud differentiation stage (T_4). The effect of different irrigation levels at various phenological stages on vegetative, yield, quality and nutritive parameters were determined. Four irrigation regimes viz., 0% ETc (I_0), 50% ETc (I_1), 75% ETc (I_2) and 100% ETc (I_3) were applied based on different percentages of Class A pan evaporation at four phenological stages viz., T_1, T_2, T_3 and T_4. The difference between water levels was 25%. The impact of different water levels applied at different growth stages on leaf parameters like the leaf area, leaf chlorophyll content and leaf nutrient levels was evaluated using the drip system of irrigation.

Sweet cherry at peak bloom stage

Sweet cherry plants at pre harvest stage

Observations

Leaf area: Leaf area was measured with the help of Systronics leaf area meter-211.

Leaf chlorophyll: Chlorophyll content in leaf samples was estimated by DMSO method given by Arnon (1949).

Leaf nutrient analysis: Leaf sampling was done in mid-July. The samples were prepared for analysis by proper washing and drying. Dried leaves were then used for chemical analysis.

Leaf N: Nitrogen was estimated by Kjeldahl method (Kjeldahl1883).

Leaf P and K: Phosphorus (P) content was determined by using ammonium-molybadate: ammonium metavanadate (Jackson 1973).

RESULTS AND DISCUSSION

Leaf area: Maximum leaf area (44.85 cm^2) was exhibited by trees receiving (I_3)100 per cent ETc level of irrigation. The highest leaf area of sweet cherry (44.65cm^2) was observed at fruit bud differentiation stage (T_4phenological stage).I_3T_4 (44.99 cm^2) treatment combination was best combination for leaf area in sweet cherry (Table 1). Leaf area increased with increased levels of irrigation during both the years of investigation. Increased leaf area under optimum irrigation regimes is due to the increased turgidity, efficient photosynthesis and production of more assimilates(Tamboli et al 2024). Increased leaf area at higher levels of irrigation might be due to better root establishment. The maximum development of leaf apparatus i.e., to reach a maximal leaf area on which the biological and the economic yields largely depend is ensured by optimal irrigation level at a particular stage. The results are in uniformity with other studies (Mishra et al 2019, Kumar and Dhillon 2023).

Leaf chlorophyll: There was significant increase in leaf chlorophyll content of sweet cherry with increased levels of irrigation. The maximum of 2.308mg/100g was recorded with 100 per cent ETc (I_3) level of irrigation and the lowest of 1.980mg/100g was obtained with 0 per cent ETc (I_0) level of irrigation. Leaf chlorophyll of sweet cherry significantly increased with different levels of irrigation. The decrease in chlorophyll content at lower irrigation regimes might be due to disorganization of chloroplasts.

Leaf nutrient content: Leaf NPK levels indicated significant variation with application of different irrigation levels at various phenological stages of growth in sweet cherry. The maximum leaf N content (2.107%), P content (0.193%) and K content (1.538%) were at 100 per cent ETc (I_3) level of irrigation. The highest leaf N content (1.901%), P content (0.208%) and K content (1.550%) were at T_4phenological stage. The interaction effect of irrigation and phenological stages also showed a significant influence on leaf N and K content of sweet cherry. The maximum leaf N and K content of 2.212 and 1.585% were obtained in I_3T_3 and I_3T_4 combination, respectively (Table 2). The results were in

Table 1. Effect of different irrigation levels at various phenological stages on leaf area (cm^2) and leaf chlorophyll (mg/100g) of sweet cherry (Pooled data for 2 years)

Year	Leaf area (cm^2)					Leaf chlorophyll (mg/100g)				
Phenological stages Irrigation levels	T_1	T_2	T_3	T_4	Mean	T_1	T_2	T_3	T_4	Mean
I_0	44.35a	44.28a	44.34a	44.43a	44.35b	1.751	1.826	2.105	2.239	1.980d
I_1	44.47a	44.55a	44.52a	44.68a	44.53a	2.143	2.207	2.225	2.296	2.218c
I_2	44.51a	44.50a	44.51a	44.65a	44.59a	2.160	2.238	2.284	2.369	2.262b
I_3	44.66a	44.74a	44.88a	44.99a	44.82a	2.173	2.288	2.302	2.470	2.308a
Mean	44.50a	44.52a	44.63a	44.65a		2.057	2.140	2.229	2.343	
CD (p=0.05)	Irrigation (I) = 0.355 Stages (T) = 0.355 I x T = 0.710					Irrigation (I) = 0.042 Stages (T) = NS I x T = NS				

T_1= Fruit set stage (15April-5May); T_2 = Pit hardening stage (6 May-25May);
T_3 = Fruit growth stage (26 May-8 June); T_4 = Fruit bud differentiation stage (1 July- 31 August)
I0 = 0 % ETc; I1 = 50 % ETc; I2 = 75 % ETc; I3 = 100 % ETc

Table 2. Effect of different irrigation levels at various phenological stages on leaf N, P and K of sweet cherry (Pooled mean for two years)

Nutrients	N (%)					P (%)					K (%)				
Phenological stages Irrigation levels	T_1	T_2	T_3	T_4	Mean	T_1	T_2	T_3	T_4	Mean	T_1	T_2	T_3	T_4	Mean
I_0	1.132	1.112	1.239	1.159	1.160c	0.173	0.152	0.180	0.193	0.174c	1.455	1.477	1.503	1.537	1.493d
I_1	1.930	1.623	1.975	2.125a	1.913b	0.173	0.160	0.187	0.197	0.179b	1.456	1.505	1.546	1.551	1.513c
I_2	1.948	1.778	2.160a	2.148a	2.009a	0.180	0.168	0.197	0.211	0.189a	1.473	1.497	1.522	1.558	1.514b
I_3	2.112a	1.930	2.212a	2.175a	2.107a	0.180	0.173	0.187	0.232	0.193a	1.495	1.523	1.550	1.585a	1.538a
Mean	1.780a	1.611c	1.896a	1.901a		0.176c	0.163d	0.188b	0.208a		1.469c	1.490d	1.530b	1.550a	
CD (p=0.05)	Irrigation (I) = 0.129 Stages (T) = 0.129 I x T = 0.258					Irrigation (I) = 0.005 Stages (T) = 0.005 I x T = NS					Irrigation (I) = 0.007 Stages (T) = 0.007 I x T = 0.014				

See Table 1 for details

uniformity with earlier study (Zaliha et al 2014). Water is essential for nutrient uptake by root interception, mass flow and diffusion also the increased availability of nutrients under high moisture conditions might have accounted for their higher uptake (Ray et al 2016). Roots intercept more nutrients when they grow in a moisture rich soil rather than in a drier soil because root growth is more extensive might be the reason for higher nutrient uptake at higher irrigation levels(Sharma and Singh 2022). The root growth, nutrient transport to rhizophere and solubility of nutrients in soils are inversely related to water deficiency in the soils, nutrient uptake and transport in the plants are negatively affected under water scarcity.

CONCLUSION

Management of irrigation for HDP is the most influential factor for yield and quality. To obtain higher yield and better quality fruits in sweet cherry, water management conditions must be improved by applying irrigation at critical phenological stages. It was observed that the higher levels of irrigation showed superiority in most of the characters including the leaf area, leaf chlorophyll and NPK Levels in sweet cherry. The fruit growth and fruit bud differentiation stages were found to be the most critical stages of irrigation in sweet cherry wherein the water stress can adversely affect the growth and development and also the irrigation at fruit bud differentiation stage may prove beneficial in increasing the subsequent year flowering and fruit set.

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AUTHOR'S CONTRIBUTION

Conceptualization of research - Rehana Javid, W.M. Wani; Designing of the experiments - G.H. Rather, Rehana

Javid; Contribution of experimental materials -W.M. Wani; Execution of field/lab experiments and data collection - Rehana Javid; Analysis of data and interpretation -R. Javid, G.H. Rather, Kounsar Javaid; Preparation of the manuscript - Rehana Javid, Kounsar Javaid.

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Water productivity and Quality of Chickpea as Influenced by Sowing Methods and Irrigation Regimes in Tarai Region of Uttarakhand

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Abstract: Chickpea (*Cicer arietinum* L.) is an essential *rabi* pulse crop in India, yet its productivity suffers from irregular rainfall. Effective irrigation management is crucial to mitigate water stress and improve crop quality, thereby enhancing food and nutritional security amid growing resource competition. This study aimed to assess the impacts of different sowing methods and irrigation regimes on the water productivity and quality of chickpea at G. B. Pant University of Agriculture and Technology during the 2017-18 season. The experiment included two sowing methods (flat bed and raised bed), two irrigation methods (check basin and sprinkler), and three irrigation stages (vegetative, pod development, and both). The raised bed sowing and sprinkler irrigation improved total and biophysical water productivity. Specifically, sprinkler irrigation achieved an increase of 51.1, 25.0, and 15.3% in total and biophysical water productivity and protein yield, respectively. Single irrigation at the vegetative stage yielded the highest total and biophysical water productivity, while protein yield was significantly greater with two irrigations.

Keywords: Chickpea, Water productivity, Sprinkler, Raised bed

In India, chickpea (*Cicer arietinum* L.) is the most important *rabi* pulse crop, grown on over 9.59 million hectares with productivity of 1151 kilograms per hectare (Department of Agriculture and Farmers Welfare 2024). Chickpea, grown as a rainfed crop, is adversely affected by irregular rainfall patterns, impacting productivity. Insufficient moisture negatively affects germination, flowering, pod development, nitrogen fixation and in-turn yield (Rani et al 2020). Chickpea can undergo forced maturity under terminal drought. Excess moisture during the vegetative stage can negatively impact emergence and growth (Zaman et al 2024), increasing disease susceptibility (Dron et al 2021), while during the reproductive stage, it can harm flowers and pods, resulting in reduced yields. Thus, both extremes of soil moisture-too much or too little-result in decreased growth, development, and yield of chickpeas. Implementing controlled irrigation is the most effective way to address the problems of inconsistent rainfall and water stress. However, this has to be done against significant challenges due to increasing competition for water resources, declining per capita water availability, and India's transition from being water-stressed to water-scarce (https://www.adriindia.org /adri/india_water_facts, Ray et al 2023). Therefore, optimizing water use is crucial to managing water stress and improving chickpea yields. Furthermore, rising concerns about malnutrition are threatening the nutritional security of the nation (Ministry of Health and Family Welfare 2022).

Modifying methods of sowing and irrigation regimes in chickpea cultivation, offers a promising approach to cope with the aforementioned challenges. The raised bed sowing method is highly effective for areas with flood irrigation. In this approach, water is applied to furrows, where it seeps laterally to the root zone, helping to control the moisture levels around the roots. Chickpea sown in 75 cm raised bed was found to 23.3% more water efficient than chickpea sown in flat bed method. This increased efficiency was attributed to the higher yield achieved with less water application in the raised bed systems compared to flat bed sowing (Kumar et al 2015). Controlled irrigation can also be achieved using sprinkler systems, which maintains an optimum depth of irrigation and hence, particularly beneficial for sensitive crops like pulses. The experiment was conducted to evaluate different sowing methods and irrigation regimes influence the water productivity and quality of chickpea.

MATERIAL AND METHODS

Experiment details: A field study was carried out at G. B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand during the *rabi* season of 2017-18. The experiment was executed in factorial randomized block design examining two method of sowing (flat and raised bed), two irrigation methods (check basin and sprinkler), and three irrigation stages (irrigation at vegetative stage, pod development stage, and both the stages). The soil was sandy loam, neutral (pH 7.02) with high organic carbon content (0.85 %), low nitrogen levels (218.5 kg/ha), high phosphorus levels (24.2 kg/ha), and medium potassium levels (182.5 kg/ha). The soil field capacity (FC) was 18.5%, while the permanent wilting point (PWP) was 6.4%.The rainfall throughout the crop growing season was only 13.6 mm.

Agronomic practices: Chickpea variety Pant Gram-186 was sown with 30 cm row spacing with seed rate 80 kg/ha. Raised beds were manually prepared with 90 cm spacing between center of two furrows, accommodating three rows per bed. Thinning was done at 15 days after sowing to maintain a plant distance of 8 ± 2 cm. Fertilizer was applied at 200 kg/ha using NPK 12:32:16, with irrigation depths 5 cm for flat beds and 3.5 cm for raised beds under check basin irrigation and 3 cm for sprinklers. The irrigations were given as per treatments. Other agronomic practices were executed as per standard recommendations.

Observations

Moisture extraction percentage: It was computed using following equation:

$$\text{Moisture extraction (\%)} = \frac{\text{Consumptive use of ith layer (cm)}}{\text{Total consumptive use (cm)}} \times 100$$

Consumptive use: The consumptive use (CU) was calculated using the formula:

$$\text{CU (cm)} = \sum_{i=1}^{n} \frac{(\text{MAi} - \text{MBi}) \times \text{BDi} \times \text{Di}}{100} + \text{ER} + \text{PMC} + (\text{Evap.} \times 0.85)$$

Where, MAi = % moisture on oven dry basis after irrigation in ith layer; MBi = % moisture on oven dry basis before irrigation in ith layer; BD = Bulk density of ith layer; Di = Depth of ith layer; n= number of layer; ER = Effective rainfall; PMC = Profile moisture contribution (Moisture at harvest – Moisture at sowing); Evap. = Evaporation; 0.85 = Correction factor

Total water productivity:

$$\text{TWP (kg/ha-cm)} = \frac{\text{Grain yield (kg/ha)}}{\text{Total water applied (cm)}}$$

Biophysical water productivity (Perry et al 2017):

$$\text{BWP (kg/ha-cm)} = \frac{\text{Grain yield (kg/ha)}}{\text{Consumptive use (cm)}}$$

Nitrogen and Protein content : The total nitrogen content was determined by modified Kjeldahl method. Thereafter protein content was determined by multiplying nitrogen content with 6.25.

Protein yield in grains : The protein yield was calculated using following formula:

$$\text{Protein yield (kg/ha)} = \frac{\text{Grain yield (kg/ha) x Protein content (\%)}}{100}$$

Statistical analysis: Analysis was carried out using R software and Fisher's least significant test was used to compare the mean values at 5% level of significance.

RESULTS AND DISCUSSION

Moisture extraction percentage: Moisture extraction percentage at depths of 0-15 cm, 15-30 cm, and 30-45 cm were 40.60, 33.39, and 26.01%, respectively, in flat beds, whereas in raised beds, they were 40.64, 31.5, and 27.86%. Moisture removal pattern from different layers was more uniform in raised beds indicating that roots were well distributed in the entire zone than flat sowing. In check basin irrigation, moisture extraction from soil depths of 0-15 cm, 15-30 cm, and 30-45 cm was 42.07, 31.93, and 26.00%, respectively. In comparison, sprinkler irrigation resulted in moisture extraction of 39.17, 32.95, and 27.87 from the same soil depths. The increased moisture extraction from deeper soil layers under sprinkler irrigation may be attributed to reduced moisture availability in the top layer and improved aeration, which encouraged roots to grow into deeper soil zones to meet crop water demands.

The average moisture extraction during two irrigations at the vegetative and pod development stages was 42.10, 31.84, and 26.06% from soil depths of 0-15, 15-30 and 30-45 cm, respectively. This pattern reflects the combined impact of the two irrigations, which increased moisture availability in the top layer. In contrast, single irrigation treatments resulted in lower moisture extraction from the top layer due to reduced moisture availability compared to treatments with two irrigations.

Water productivity: Raised bed systems exhibited greater total and biophysical water productivity, yielding 213.9 and 78.2 kg/ha-cm, respectively, compared to flat beds, which yielded 180 and 76.6 kg/ha-cm. This can be attributed to a slightly higher grain yield though non-significant in the raised bed, likely due to improved sunlight penetration and optimal moisture and aeration levels in the rhizosphere. The average moisture content 48 hours after irrigation was higher in the flat bed (15.82%) compared to the raised bed (13.86%). The

Table 1. Moisture extraction pattern (%) under different sowing, irrigation methods and stages

Treatment	0-15 cm	15-30 cm	30-45 cm
Sowing method			
Flat bed	40.6	33.39	26.01
Raised bed	40.64	31.5	27.86
Irrigation method			
Check basin	42.07	31.93	26.00
Sprinkler	39.17	32.95	27.87
Irrigation stage			
Vegetative	39.31	32.20	28.49
Pod development	40.46	33.28	26.26
Both	42.10	31.84	26.06

lower soil moisture in raised beds suggests that sensitive crops like chickpeas will thrive better in raised bed systems than in flat sowing but may be due to less rainfall, significant changes could not be found (Agrawal et al 2022). Sprinkler irrigation was associated with significantly higher grain yields and reduced water application, resulting in 51.1% higher total water productivity and 25.03% greater biophysical water productivity. Under sprinkler irrigation, the controlled and uniform water supply likely enhanced the crop's micro-climate, promoting efficient water and nutrient use. In terms of soil moisture, check-basin irrigation resulted in an average of 16.74% moisture 48 hours after irrigation, compared to 12.94% with the sprinkler method. Since chickpeas are highly sensitive to moisture stress, they may have suffered from excess moisture in the root zone with check-basin irrigation. Furthermore, this method may lead to soil particles settling more tightly, reducing airflow in the rhizosphere and potentially causing stunted growth in the plants (Agrawal et al 2022).Significantly higher water productivity was found in sprinkler irrigation over check basin irrigation based on two years study in chickpea in sandy loam soil of Morena (Madhya Pradesh) (Singh et al 2017).

Two irrigations at the vegetative and pod development stages led to the highest total water applied (8.61 cm) and consumptive use (17.80 cm), which corresponded to lower total and biophysical water productivity, respectively. Irrigations during the vegetative and pod development stages led to grain yields that were significantly higher by 17.15% and 22.10%, respectively, compared to a single irrigation at either stage. Providing two irrigations at these critical points ensured a better moisture supply, which helped prevent prolonged stress on the chickpea crop. Both growth and yield attributes were significantly enhanced, ultimately boosting overall yield (Agrawal et al 2022). Singh et al (2024) revealed that irrigation water productivity of two irrigations at branching and pod development stages is lowest as compared to single irrigation at either stages. Total and biophysical water productivity improved as the number of irrigations decreased. The single irrigation at the vegetative stage achieved the highest total and biophysical water productivity (232.5 and 82.4 kg/ha-cm, respectively) due to the lowest consumptive use (14.08 cm), lower total water applied (4.99 cm), and higher yield compared to a single irrigation at the pod development stage.

Quality parameters: Sowing methods and irrigation regimes did not have a significant effect on the nitrogen (N) content in the grain. There were no significant differences in the protein content of the grains across the treatments, consistent with the lack of significant variation in nitrogen content. The protein yield among the various sowing, did not differ significantly although a slightly higher protein yield was observed with the raised bed method compared to the flat bed method. Protein yield was significantly greater in the sprinkler irrigation system (272 kg/ha) compared to the check basin irrigation (236 kg/ha), which was attributed to the significantly higher grain yield in the former. Singh et al (2017) reported that significantly higher protein yield was in sprinkler irrigation over check basin. Protein yield was significantly higher with two irrigations at the vegetative and pod development stages (287 kg/ha) compared to a single irrigation at either the vegetative stage (242 kg/ha) or the pod development stage (234 kg/ha).

Table 2. Water productivity and quality parameters of chickpea as influenced by different sowing methods, irrigation methods and application stages

Treatment	Total water applied (Irrigation + Rainfall) (cm)	Consumptive use (cm)	Total water productivity (kg/ha-cm)	Biophysical water productivity (kg/ha-cm)	N content (%)	Protein content (%)	Protein yield (kg/ha)
Sowing method							
Flat bed	6.69	15.72	180.0	76.6	3.35 [a]	20.96 [a]	252 [a]
Raised bed	5.69	15.56	213.9	78.2	3.37 [a]	21.05 [a]	257 [a]
Irrigation method							
Check basin	7.03	16.28	160.0	69.1	3.36 [a]	20.99 [a]	236 [b]
Sprinkler	5.36	15.00	241.8	86.4	3.36 [a]	21.02 [a]	272 [a]
Irrigation stage							
Vegetative	4.99	14.08	232.5	82.4	3.34 [a]	20.90 [a]	242 [b]
Pod development	4.99	15.05	223.0	74.0	3.36 [a]	20.98 [a]	234 [b]
Both	8.61	17.80	157.8	76.3	3.38 [a]	21.14 [a]	287 [a]

Values followed by different lowercase letters (a-b) are significantly different at 5%

CONCLUSION

The raised bed and sprinkler irrigation are beneficial for water sensitive crops like chickpea. Moreover, two irrigations at vegetative and pod development stages are advantageous for obtaining higher protein yield of chickpea.

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Auxins Treatment of Hardwood Cuttings of *Bougainvillea* for Inducing Rooting

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***Abstract*:** In present studies, auxins were used to allow rooting in hard to root *Bougainvillea* varieties viz. Shubra, Lady Mary Bearing and Zakiriana. Hardwood cuttings of these varieties were treated with different auxins concentrations and combination with dipping them for a long duration (for 12 hours) with lower concentrations and then planted in polybags containing garden soil. The cuttings treated showed that NAA+IBA (100+100 ppm) resulted in maximum shoot emergence (40.00%) among all the treatments. The treatment with IBA 500 ppm resulted in maximum mean number of shoots (1.86), mean shoot length (7.11 cm), number of branches (1.84), number of roots (3.07). The maximum mean per cent establishment (35.56%) of plants was in combination treatment with NAA+IBA (100+50) ppm. Among all the three varieties, Zakiriana recorded maximum shoot emergence , number of shoot, ae shoot length number of leaves , number of branches , number of roots , length of roots and establishment of plants . This indicated that higher concentrations upto 500 ppm are more beneficial along with higher concentration combinations i.e. NAA+ IBA (100+100) ppm. IBA showed better results than NAA.

Keywords: *Bougainvillea*, Rooting, Hardwood, Auxins

Bougainvillea is very versatile plant, originated in South America, belongs to family Nyctinaginacea, has 14 species and 3 are horticulturally important: *B spectabilis* Willdenow, *B glabra* Choisy and *B peruviana* Humboldt and Bonpland (Heimerl 1900). *Bougainvillea*is a very hardy shrub most popular to be used as roadside plant, for shrubbery border, as standard shrub or as a beautiful pot plant or as hanging baskets too. Mainly for propagation, hardwood and semi-hardwood cuttings are used. In general, *Bougainvillea* is easy to root but few varieties are difficult to root, so they are treated with auxins solutions to initiate rooting in these difficult to root varieties. Use of growth regulators is crucial for floriculture industry. Auxins increases cell divisions and also cell enlargement, and results in hydrolysis of carbohydrates, accumulation of metabolites and synthesis of new proteins at site of application of auxins (Root tips). Auxin only initiates the rooting but do not increase the size of already sprouted roots but are helpful in stimulating adventitious root formation. Root promoting methods are mostly used to basal portions of cutting by using liquid and talc formulations of auxins (Naija et al 2009). An extended basal method may be utilized to for some difficult-to-root species, Hartmann et al (2002) and Ibironke (2019)also reported that root initiation in cuttings of *Bougainvillea* could be enhanced with IBA or dipped coconut water for 5 minutes enhanced growth. Auxins treatments are helpful as a conservative strategy to save those species which are otherwise difficult to root naturally. Shekhawat and Manokari (2016) first reported of vegetation propagation of *Couroupita guianensis*and its conservation and sustainable utilization of this medicinal tree. The objective of study is find out best rooting media for propagating *Bougainvillea* hardwood cuttings by dipping cuttings for long durations (12 hours) by using lower concentrations of auxins.

MATERIAL AND METHODS

In this study, hardwood cuttings of three varieties of *Bougainvillea* i.e. Shubra, Lady Mary Baring and Zakiriana were treated with auxins solutions for rooting as these are hard to root varieties. The hardwood cuttings (8-10˝ long) of pencil thickness were be prepared during Jan-Feb, 2016 at Punjab Agricultural University by giving slanting cut at the upper end and straight cut below the basal bud and then planted in the polythene bagsin factorial completely randomized block design and each treatment was replicated thrice. Different solutions of auxins were IBA (Indole butyric acid) (100, 300 and 500 ppm) and NAA (Naphthalene acetic acid) (100, 300 and 500ppm) and their combinations i.e. NAA+IBA (50+100 ppm), NAA+IBA (100+50 ppm) and NAA+IBA (100+100 ppm) were used and cuttings were dipped for 12 hours with control (distilled water) and parameters of plants for rooting were taken after 4months of planting.

Statistical analysis: The data were analyzed by software CPCS1 and by Duncan's Multiple Range Test (DMRT).

RESULTS AND DISCUSSION

The hardwood cuttings of all three varieties of *Bougainvillea* viz. Shubra, Lady Mary Baring and Zakiriana planted after auxins treatments (long duration; 12h) exhibiting sprouting and (Table 2). The treatment of cuttings with auxins had significant effect on shoot emergence. The mean shoot emergence was maximum in NAA+IBA (100+100 ppm) (40.00%) and minimum in NAA 100 ppm (15.56%), irrespective of the varieties. The difference was significant among varieties, maximum in Zakiriana (44.33%) and followed by Lady Mary Baring and Shubra irrespective of auxins treatment. Renuka and Sekhar (2014)observed effect of IBA and NAA at different concentrations on the rooting of carnation (*Dianthus caryophyllus* L.) cuttings of cv. Dona recorded that IBA 200 ppm and IBA 100 ppm + NAA 50 ppm superseded the rest. Kumari et al (2013) reported in *Jatropha curcas* that IBA (200 ppm) resulted in early emergence of shoots, sprouting and rooting.

The treatment of cutting with auxins had non-significant effect on number of shoots per cuttingrecorded at monthly intervals (Table 1). The mean number of shoots was maximum in IBA 500 ppm (1.86) and minimum in control (0.98), irrespective of the varieties. The difference among varieties was significant, the maximum was in Zakiriana (1.69), followed by Lady Mary Baring . Shubra. Singh (2000) also reported thattreatment of cuttings with IBA (500 ppm) in *Bougainvillea peruviana* cv. Shubra resulted in number of shoots per cutting (1.37).

Auxinstreatment significantly affects the average shoot length and number of leaves as at monthly intervals (Table 1). The mean shoot length varied from to IBA 500 ppm to NAA+IBA (100+100 ppm) with non-significant differences. The minimum was in control (1.95 cm), irrespective of the varieties. The difference among varieties was non-significant and maximum shoot length was obtained in Zakiriana (6.12 cm), followed by Lady Mary Baring and Shubra, irrespective of auxins treatment. The number of leaves was at par in treatments but significantly better than the control (10.96), irrespective of the varieties. The difference had significant effect among the varieties, and was maximum was in Zakiriana, followed by Lady Mary Baring and Shubra, irrespective of auxins treatment.Singh (2000) reported in *Bougainvillea peruviana* cv. Shubra that the treatment of cuttings with IBA (500 ppm) resulted in significantly more sprouting and average shoot length.

Significant effect was observed by treating the cuttings with auxins on per cent of cutting exhibiting rooting and number of roots but treatments showed non-significant effect on average length of root (Table 3). The mean per cent of cutting exhibiting rooting was maximum in NAA+IBA (100+50 ppm) 40.00%) and minimum in control (15.60%), irrespective of growth regulator treatment. The difference among the varieties had significant effect on per cent of cutting exhibiting rooting and the maximum was in Zakiriana (43.40%), followed by Lady Mary Baring and Shubra, irrespective of auxins treatment. The mean number of roots was at par in all the treatments but was significantly better than all other treatments, however, minimum was in NAA 300 ppm (2.09), irrespective of the varieties. The difference among varieties was non-significant for number of roots, maximum was in Zakiriana (2.64), followed by Lady Mary Baring and Shubra,

Table 1. Comparative effect of different auxins treatments (12h) on number of shoots and hoot length (cm) in *Bougainvillea*

Treatments (ppm)	Number of shoots				Average shoot length (cm)				Number of leaves			
	Shubra	Lady Mary Baring	Zakiriana	Mean	Shubra	Lady Mary Baring	Zakiriana	Mean	Shubra	Lady Mary Baring	Zakiriana	Mean
NAA 100	0.67	1.52	1.85	1.35	3.30	4.73	4.09	4.04^{bcdefghi}	9.67	26.12	29.37	21.71^{abcdef}
NAA 300	0.33	2.06	1.87	1.42	3.27	6.56	6.10	5.31^{abcdfg}	4.67	31.86	35.95	24.16^{abcdef}
NAA 500	1.00	2.50	1.75	1.75	5.70	4.58	6.20	5.49^{abcdef}	16.17	27.33	32.44	25.13^{abcd}
IBA 100	0.67	1.44	1.91	1.34	4.03	4.89	7.67	5.53^{abcde}	10.67	29.28	34.83	24.93^{abcde}
IBA 300	1.17	1.89	1.75	1.60	6.08	8.79	5.68	6.85^{ab}	18.50	26.89	36.50	27.30^{ab}
IBA 500	1.67	2.00	1.92	1.86	7.32	5.99	8.01	7.11^{a}	19.83	28.45	27.66	25.32^{abc}
NAA+IBA (50+100)	1.67	1.28	1.40	1.45	7.73	3.98	7.57	6.43^{abc}	25.67	28.00	32.77	28.81^{a}
NAA+IBA (100+50)	0.67	1.87	1.58	1.37	3.27	5.95	7.82	5.68^{abcd}	9.67	26.03	32.26	22.65^{abcdef}
NAA+IBA (100+100)	1.33	1.50	1.28	1.37	3.73	6.38	5.06	5.06^{abcdefgh}	14.00	24.61	29.78	22.80^{abcdef}
Control	0.78	0.56	1.61	0.98	1.30	1.58	2.97	1.95^{ij}	8.00	8.44	16.44	10.96^{j}
Mean	1.00^{c}	1.66^{b}	1.69^{a}		4.57	5.34	6.12		13.68^{c}	25.70^{b}	30.80^{a}	
CD (p=0.05)	Varieties (A)=0.34; Auxins treatments concentrations (B)= NS; Interaction (A×B)= NS				Varieties (A)= NS; Auxins treatments concentrations (B)=2.90; Interaction (A×B)= NS				Varieties (A)=4.50; Auxins treatments concentrations (B)=8.21; Interaction (A×B) = NS			

*Different letters in each column are significantly different at P≤0.05 by Duncan's Multiple Range Test (DMRT) irrespective of the varieties. The mean shoot length of root (cm) was the maximum in IBA 300 ppm (12.76 cm) and minimum was in control (4.96 cm), irrespective of the varieties. The difference among the varieties was significant with respect to shoot length, however, the maximum shoot length was in Zakiriana (13.25 cm), followed by Lady Mary Baring and Shubra, irrespective of the auxins treatment. Shabha and Alshammary (2013) reported in *Bougainvillea* cv. Shubra that treatment of cuttings with IBA (500 ppm) resulted in the highest rooting percentage and more number of roots per cutting. Singh (2000) reported in *Bougainvillea peruviana* cv. Shubra, the treatment of cuttings with IBA (500 ppm) resulted in significantly more rooting (57.5%).

The treatment of cutting with auxins had significant effect

Table 2. Comparative effect of different auxins treatments on a percentage sprouting and percent establishment of plants in *Bougainvillea* at after 1 and 4 months

Treatments (ppm)	Percent sprouting in cuttings				Percent establishment of plants			
	Shubra	Lady Mary Baring	Zakiriana	Mean	Shubra	Lady Mary Baring	Zakiriana	Mean
NAA 100	6.67	36.67	40.00	27.78^{e}	6.67	33.33	33.33	24.44^{e}
NAA 300	3.33	30.00	43.33	25.56^{f}	3.33	26.67	43.33	24.44^{e}
NAA 500	13.33	16.67	63.33	31.11^{c}	13.33	16.67	63.33	31.11^{b}
IBA 100	6.67	23.33	33.33	21.11^{g}	6.67	20.00	26.67	17.78^{g}
IBA 300	16.67	13.33	30.00	20.00^{h}	16.67	13.33	30.00	20.00^{f}
IBA 500	20.00	26.67	40.00	28.89^{d}	20.00	20.00	40.00	26.67^{d}
NAA+IBA (50+100)	16.67	30.00	50.00	32.22^{b}	13.33	30.00	40.00	27.78^{c}
NAA+IBA(100+50)	6.67	26.67	86.67	40.00^{a}	6.67	23.33	76.67	35.56^{a}
NAA+IBA (100+100)	6.67	16.67	30.00	17.77^{i}	6.67	16.67	26.67	16.67^{h}
Control	10.00	10.00	26.67	15.56^{j}	6.67	6.67	16.67	10.00^{i}
Mean	10.67^{c}	23.00^{b}	44.33^{a}		10.00^{c}	20.67^{b}	39.67^{a}	
CD (p=0.05)	Varieties (A)= 0.54; Auxins treatments concentrations (B)=0.98; Interaction (A×B)= 1.70				Varieties (A)= 0.47; Auxins treatments concentrations (B)= 0.85; Interaction (A×B)= 1.48			

Different letters in each column are significantly different at P≤0.05 by Duncan's Multiple Range Test (DMRT)

Table 3. Comparative effect of different auxins treatments on a percent of cutting exhibiting rooting, number of roots and average length of roots (cm) of plants in *Bougainvillea* after 4 months

Treatments (ppm)	Per cent of cutting exhibiting rooting				Number of roots				Average length of roots (cm)			
	Shubra	Lady Mary Baring	Zakiriana	Mean	Shubra	Lady Mary Baring	Zakiriana	Mean	Shubra	Lady Mary Baring	Zakiriana	Mean
NAA 100	6.67	36.70	40.00	27.88^{e}	2.33	2.48	2.74	2.52^{abcd}	6.03	10.60	9.08	8.57
NAA 300	3.33	30.00	43.33	25.66^{f}	1.00	2.75	2.52	2.09^{abcdefghi}	3.40	15.29	13.65	10.78
NAA 500	13.33	16.77	63.33	31.11^{c}	2.83	3.00	2.44	2.76^{abc}	7.48	10.88	13.98	10.78
IBA 100	6.67	23.33	33.33	21.11^{g}	2.00	2.56	2.89	2.48^{abcef}	4.90	11.73	17.19	11.27
IBA 300	16.70	13.33	30.00	20.00^{h}	3.00	2.56	3.25	2.93^{ab}	9.00	16.54	12.75	12.76
IBA 500	20.00	26.70	40.00	28.90^{d}	3.50	2.78	2.91	3.07^{a}	10.33	12.12	13.36	11.70
NAA+IBA (50+100)	16.70	30.00	50.00	32.22^{b}	3.00	2.14	2.40	2.51^{abcde}	11.82	9.47	16.02	12.43
NAA+IBA (100+50)	6.67	26.70	86.70	40.00^{a}	1.33	2.53	2.60	2.16^{abcdefgh}	3.90	13.51	16.61	11.34
NAA+IBA (100+100)	6.67	16.70	30.00	17.80^{i}	1.67	1.94	3.16	2.26^{abcdefg}	5.37	13.59	11.07	10.01
Control	10.00	10.00	26.70	15.60^{j}	0.83	0.67	1.50	2.15^{abcdefghi}	2.79	3.30	8.79	4.96
Mean	10.70^{c}	23.00^{b}	43.40^{a}		2.15	2.34	2.64		6.50^{c}	11.70^{b}	13.25^{a}	
CD (p=0.05)	Varieties (A)= 0.54;Auxins treatments concentrations (B)= 0.98; Interaction (A×B)= 1.70				Varieties (A)= NS; Auxins treatments concentrations (B)=0.99; Interaction (A×B)= NS				Varieties (A)= 2.70; Auxins treatments concentrations (B)= NS; Interaction (A×B)= NS			

*Different letters in each column are significantly different at P≤0.05 by Duncan's Multiple Range Test (DMRT) on per cent establishment of the cutting (Table 2). The mean per cent establishment was maximum in NAA+IBA (100+50) ppm (35.56%) and minimum in control (10.00%), irrespective of the varieties. The difference among varieties had significant effect and the maximum was in Zakiriana (39.67%), followed by Lady Mary Baring and Shubra, irrespective of growth regulator treatment. Similarly, Shabha and Alshammary (2013) reported in *Bougainvillea* cv. Shubra that treatment of cuttings with IBA (500 ppm) resulted in the highest establishment percentage. Singh (2000) reported in *Bougainvillea peruviana* cv. Shubra that the treatment of cuttings with IBA (500ppm) resulted in significantly more establishment of plant (51.67%) than all other treatment.

CONCLUSION

The auxins treatment of hardwood cuttings of *Bougainvillea* by using lower concentrations for long duration (12h) method was the best percent rooting in NAA+IBA (50+100 ppm) and establishment of plants (%) was maximum in NAA+IBA (100+50 ppm).It is more beneficial to have more number of roots to have successful transplant as compared to length of roots, as with increasing number of roots, surface area to absorb nutrients and water from soil is more as compared with long roots, thus IBA 500 ppm is beneficial from this point of view having highest number roots and can be used in much easier way than making combinations. The study showed that either combinations or higher concentrations can be used for good results.

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Cost-Benefit Analysis of Irrigation and Nitrogen Scheduling in Wheat (*Triticum aestivum* L.) Cultivation

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Abstract: Field experiment was conducted to study the effect of irrigation and nitrogen scheduling on cost of cultivation, net return and benefit cost ratio of wheat crop, at Department of Agriculture, Mata Gujri College, Fatehgarh sahib, Punjab, India, during *rabi* season of 2019-20. The gross return, net return and B: C ratio was maximum under the irrigation schedule I_4- irrigation at CRI, tillering, flowering and milking stage*fb* I_3- Irrigation at CRI, tillering and late jointing stage and significantly superior to other treatments. Minimum gross return, net return and B: C ratio was in irrigation schedule I_1- irrigation at CRI. Among nitrogen splits, results revealed that the maximum gross return, net return and B: C ratio in N_3- Four splits of nitrogen *fb* N_2- three splits of nitrogen was significantly superior over N_1- two splits of nitrogen. Higher yield of crop with proper moisture and nutrient availability gave better economic returns of the crop as compared to the treatments where moisture was insufficient at critical stages.

Keywords: Economics, Irrigation, Nitrogen, Wheat, *Triticum aestivum*

Wheat cultivation has been symbolic of the green revolution and self sufficiency in food production (Sulochna et al 2018). Maximum yield of crop may not always be the ultimate goal. In modern farming profit is more important factor than the maximum yield. The response of yield to nitrogen supply is influenced by environmental conditions, especially the quantity and timing of water availability to the crop. In wheat, recovery of nitrogenous fertilizer can be significantly increased by applying nitrogen at critical growth stages of wheat (Abourached et al 2008). Proper irrigation scheduling is important practice for improving water use efficiency, utilization of energy and other production inputs. Major factors influencing irrigation schedule are water requirement of crop; availability of water for irrigation; and capacity of the root zone to store water. Water needs of crop are of great importance for determining the time of irrigation during the crop growing season. The different levels of irrigation and soil fertility have significant effect on economic of crop (Chakmas et al 2018). Thefour irrigations at crown root initiation, late tillering, flowering and milk stages produced maximum income over three irrigations production efficiency and net income were also higher (Jain et al 2018).

Availability of nitrogen at critical stages and its management plays an important role in improvement of crop growth, environmental safety and economics of crop production (Maqsood et al 2012). Nitrogen scheduling plays an important role in growth, productivity of wheat as well as on its use efficiency. Due to highly mobile it losses through various ways response of wheat to split application of nitrogen with reduced basal dose has been reported by several workers in India. Nitrogen is extremely mobile nutrient; it suffers more losses due to leaching, runoff and volatilization etc. The nitrogen use efficiency varies from 30-50% (Zain et al 2021). Split nitrogen application improves utilization by crops while lowering fertilizer loss due to leaching and volatilization (Si et al 2020). Water and fertilizer application during important crop growth stages could improve the physiological and biochemical characteristics of the crop, and eventually improve yield (Li et al 2023). The present study was carried out to investigate the influence of different irrigation and nitrogen schedules on economics of wheat crop.

MATERIAL AND METHODS

Field experiment was conducted at research farm of Mata Gujri College, Shri Fatehgarh Sahib, Punjab, India. The location coordinates are 30º65'N latitude, 76º39' E longitudes. The crop was grown in*rabi*season of 2019-20. The experiment was laid out in split plot design with four irrigation schedules and three spits of nitrogen i.e. total twelve treatment combinations replicated thrice. The recommended dose of fertilizers for wheat crop was 120, 60 and 40 kg ha^{-1} of N, P_2O_5 and K_2O respectively. The treatment details are as:Irrigation scheduling: I_1- Irrigation at CRI, I_2- irrigation at CRI and tillering, I_3- Irrigation at CRI, tillering and late jointing stage, I_4- Irrigation at CRI, tillering, flowering and at milking stage. Nitrogen scheduling: N_1- Nitrogen in two splits, N_2- Nitrogen in three splits, N_3- Nitrogen in four splits.Full doses of P and K fertilizers were applied at sowing time and nitrogen was applied as per the treatments in different sub plots. First dose of nitrogen was applied as basal dose; second dose was applied at CRI, third at late jointing and fourth at flowering stage in different plots in combination with irrigation. Regular biometric observations were recorded at periodic intervals of 30, 60, 90 DAS and at harvest stage. Yield parameters were recorded just before the harvesting of crop. The grain yield of each plot was recorded and converted in hectare.

Statistical analysis: The statistical analysis was performed using Microsoft Excel.. Statistical significance between treatments for various parameters was analyzed using critical differences at 0.05 probability level.

Economic analysis: Relative economics of different treatments were worked out on the basis of grain and straw yield per hectare. The cost of inputs and outputs were estimated on prevailing market rates. The Benefit: Cost ratio was calculated:

Benefit: Cost ratio = Net returns (₹/ha)/Cost of cultivation (₹/ha)

Total cost of cultivation was calculated by adding the cost of variables (involved in each operation/input) in the common cost. Gross return was estimated by converting the economics yield of wheat crop (grain and straw) into monetary terms on the basis of support price of wheat grain and prevailing local market price for straw and expressed as per hectare.

RESULTS AND DISCUSSION

Effect of irrigation scheduling: The different treatments significantly affected the economics of crop except the cost of cultivation (Table 1). The highest gross return, net return and benefit cost ratio was observed in I_4- Irrigation at CRI, tillering, flowering and milking stage which was at par with I_3- Irrigation at CRI, tillering and late jointing stage and significantly superior to remaining treatments. This might due to the proper availability of moisture at critical stages resulted in higher growth and yield parameters that gave better economic benefits as compared to other treatments. Balkrishna et al (2023) reported that irrigation schedules significantly effect on economics of wheat. The higher return was observed when irrigation was applied at CRI stage and before flowering of wheat and was significantly superior over rest of treatments.Application of only one irrigation at crown root initiation stage resulted in lower nutrient uptake that gave poor yield of crop. Theirrigations applied at crown root initiation, late tillering, flowering and milk stages produced higher income over three irrigations (Jain et al 2018). Kumar et al (2017) observed the increase in irrigation number from one to four increased the grain yield of wheat.

Effect of nitrogen scheduling: The different nitrogen schedule have significant effect on the economics of crop except cost of cultivation (Table 1). The highest gross return, net return and benefit cost ratio was observed in N_3- four splits of nitrogen which was at par with N_2- three splits of nitrogen at critical growth stags of the crop which was significantly superior over rest of treatments (Table 1). The higher net returns with four splits of nitrogen application was due to steady supply of nitrogen which synchronized with the peak period of nitrogen requirement that had resulted in higher yield which fetched higher prices. Mathukia et al (2014) also reported higher net returns and benefit: cost ratio with the application of nitrogen @ 120 kg/ha in 3 splits. The lowest cost of cultivation, gross return, net return and benefit cost ratio werein N_1- two splits of nitrogen. The lower return was after split application of nitrogen as most of the nitrogen is lost by leaching, when applied 50% as basal dose the crop cannot receive nitrogen at later stage for growth thus reduction in yield.

Economic benefits from split application of nitrogen can be observed by higher nutrient availability at critical stages of crop that increased vegetative growth as well as yield of the crop as compared to application of fertilizer at sowing time or in two splits. Applying all the fertilizer quantity of recommended fertilizer not only waste essential nutrients but

Table 1. Gross return, net return and benefit cost ratio as affected by irrigation and nitrogen scheduling

Treatments	Cost of cultivation	Gross return (₹)	Net return (₹)	B:C ratio
Main plot (Irrigation scheduling)				
I_1-Irrigation at CRI (Crown root initiation)	46289	85123	38834	0.84
I_2- Irrigations at CRI and tillering stage	46589	92356	45766	0.98
I_3- Irrigations CRI, tillering and late jointing stage	46889	99141	52251	1.11
I_4- Irrigations at CRI, tillering,flowering and milking stage	47189	105473	58284	1.23
CD (p= 0.05)	-	9443	9443	0.20
Sub plot (nitrogen scheduling)				
N_1- Two splits of nitrogen	46439	87482	41042	0.88
N_2- Three splits of nitrogen	46739	97988	51248	1.10
N_3- Four splits of nitrogen	47039	101100	54060	1.15
CD (p= 0.05)	-	8133	8133	0.17

also leads to environmental pollution by leaching in water resources and soil layers. Less availability of fertilizer nutrients results in poor grain yield as proved to be economically less beneficial to farmers as cost of fertilizer remain same in both cases. Verma et al (2018) observed that the split application of nitrogen (33%N at sowing + 33%N at 30 DAS +33% at 60 DAS) recorded significantly the highest gross returns .net return, and B:C. Akhter et al (2017) concluded, Kashmir 3 splits of nitrogen in the ratio of 25:50: 25 (basal + active tillering + booting) resulted in highest gross returns, net returns and benefit: cost ratio followed by the treatment where nitrogen was applied in the ratio of 50: 25: 25 (basal + jointing + booting).Agronomic use efficiency, nitrogen utilization efficiency and grain protein content in wheat were significantly affected by split application of nitrogen over control treatment revealed by (Hundal and Kang 2019). Irrigation water plays a crucial role in development of wheat plant during critical growth stages form germination of seed to maturation. Irrigation applied at critical growth stages would be valuable management practice for improving yield of wheat crop (Zain et al 2021). Deficiency of nitrogen has greater impact on grain yield and yield attributes by affecting the production of biomass and solar radiation use efficiency of the crop plant (Heinemann et al 2006). Soil and climatic variability and conditions associated with processes that affect nitrogen dynamics in the soil and their relationship with the plant may cause changes in nitrogen availability and its requirement of the plant.

CONCLUSION

The irrigation scheduling at CRI, tillering, flowering and milking stage with four nitrogen split have significant impacts on production economics of wheat. The highest gross return, net return and benefit cost ratio were recorded in these combinations (I_4 N_3). The benefits depend on the cost of irrigation and nitrogen inputs relative to the increase in yield and revenue. In general, efficient irrigation and precise nitrogen scheduling improve the benefit-cost ratio, but the exact impact can vary based on specific conditions such as local water availability, fertilizer costs and yield potential.

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Performance of Plum (*Prunus salicina* L.) Genotypes in Subtropical North-Western India (Punjab)

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***Abstract*:** The present investigations were carried out at Punjab Agricultural University, Ludhiana during 2022-2023. Plants of seven plum genotypes were evaluated for their vegetative, flowering, fruiting, and yield characteristics. Maximum tree height and tree volume was in genotype Manake Lalri. Fruit maturity of existing cultivars of Punjab (Satluj Purple and Kala Amritsari) coincided with Frontier and Sharps Early. Genotype Sharps Early recorded maximum fruit set and high fruit retention. The time of harvesting of existing cultivars of Punjab - Satluj Purple and Kala Amritsari (pollinizer) almost coincided with genotypes Frontier and Sharps Early (1st fortnight of May). Apart from Kala Amritsari, other self-compatible genotypes were Sharps Early, Frontier, Manake Lalri, and Kataru Chak. Genotypes Frontier, and Manake Lalri exhibited freestone characteristic. Fruit yield was highest in Kala Amritsari followed by Satluj Purple, Frontier and Sharps Early. Fruit weight was maximum in Satluj Purple followed by Frontier and Sharps Early. Plum genotypes Sharps Early and Frontier are self-compatible, performed better than other genotypes in terms of maturity, yield and fruit quality and can be further evaluated under Punjab conditions.

Keywords: Plum, Genotypes, Self-compatible, *Prunus salicina*

The plum is an important stone fruit of temperate and sub-tropical regions of the world of Rosaceae family, sub family Prunoidea, order Rosales and genus *Prunus*. It ranks second to peaches in terms of economic importance, among all stone fruits (Vishnu et al 2012). It is a deciduous fruit crop, grown in areas having chilling cold winters and dry, hot summer season. There are 20-40 species of plum distributed in different parts of the world, but the main species of plum for commercial production are Japanese plum (*Prunus salicina* Lindl.) and European plum (*Prunus domestica* L.). These two species differ in their requirement of chilling hours and ploidy levels *viz*. the Japanese plum being diploid (2n=2x=16) and the European plum, hexaploid (2n=6x=48). The European plum is a diploid hybrid of *Prunus cerasifera* and *Prunus spinosa*. It thrives best at 1300-2000 m above mean sea level and requires 1000-2000 chilling hours during winter season. The center of origin of Japanese and European plum has been reported to be China and Asia minor, respectively. Major plum producing countries are China, European Union, USA, Serbia, Chile and Romania.Plum is usually a fruit crop of temperate region but it is being grown in both temperate and sub-tropical climate. Japanese plums are widely cultivated plum species in India. The fruits are an excellent source of vitamin K, C, A, minerals like potassium, antioxidants, dietary fibres and chemicals like tryptophan, quercetin and sorbitol, which regulate various body mechanisms and processes (Prajapati et al 2012). In India, it is commercially grown in warm temperate and and sub-tropical parts of Himachal Pradesh, Uttarakhand, Jammu and Kashmir, Haryana and Punjab. Genotypes which require more than 300 chilling hours are commercially grown in temperate regions whereas those which require less than 300 chilling hours in the sub-tropical climate. In Punjab, sub-tropical plum is grown on area of 399 ha with an annual production of 7041 MT (Anonymous 2021). It is mainly cultivated in districts of Amritsar, Jalandhar, Gurdaspur, Hoshiarpur, Patiala and Kandi belt of Punjab. Plum cultivation in India and Punjab is gaining widespread popularity. It has become an important commercial fruit crop and its taste is cherished by consumers in fresh as well as processed form. Plum fruits are diverse in color, flavor, fruit size, aroma, and thus, is quite desirable in terms of fruit quality (Gonez-Pleza and Ledbetter 2010). The plum industry of Punjab is based on a single cultivar 'Satluj Purple'. It is self-unfruitful, low chilling and an early ripening variety which comes into the market when other fruits are scarce. There is a need to introduce new genotypes to break the monoculture of single variety of plum in the state. Plant introduction is an efficient method of plant breeding. Thus, screening and evaluation of germplasm on the basis of various morphological and physiological characteristics is an important step in introduction of a new variety. Newly introduced genotypes do not perform well until their performance, and character attributes are studied keenly under their new habitat and climate. Varietal characteristics such as fruiting behaviour, growth habits, yield characters, flowering behavior of any cultivar may depend on soil, climate, water table, rainfall, atmospheric parameters like temperature and humidity. Thus, performance of a variety may vary from one state to another depending on agro-climatic conditions. This study is conducted in order to find out one or more genotypes which may perform well in terms of quality and yield parameters under Punjab conditions.

MATERIAL AND METHODS

The study was conducted on 9 years old, uniform trees of seven plum genotypes viz. Sharps Early, Frontier, Manake Lalri, Kataru Chak, Yellow Alubokhara, Satluj Purple and Kala Amritsari at, Punjab Agricultural University, Ludhiana, Punjab during the year 2022. Four trees planted at a spacing of 5×5m, per genotype were selected to serve as four replications. The university is situated at a latitude and longitude of 30º 90'N and 75º 80'E, respectively at an elevation of 244 m above mean sea level. The sub-tropical region provides 733 mm rainfall along with 250 to 300 chilling hours to plum trees annually. The maximum temperature rise is observed in the months of May-June (≥45ºC) while the minimum in January (≤ 5ºC). The experiment was laid out in completely randomized block design .The data was analyzed using SAS 9.3 software. The genotypes were analyzed and observed for their vegetative, flowering, fruiting and yield characteristics by using the techniques given below:

Tree height, girth and volume: The tree height was determined with the help of measuring pole while a measuring tape was used to measure tree girth. Tree volume was determined by formula mentioned by Kishor et al (2018).

Period of leaf fall and emergence: Period of leaf fall consisted of days when 10% of leaves were shed till more than 90% of leaves had fallen off while leaf emergence was noted from the date when 10% of the leaves were sprouted till the tree regained 90% of the foliage.

Start of flowering, full bloom: Start of flowering was observed when 5 per cent flower buds opened on the tree and when 75 per cent flowering had taken place, the date was recorded for full bloom.

Fruit set percentage: Four branches were tagged on each side of the tree and the total flowers were counted on each branch. The fruit set was recorded two weeks after full bloom and calculated by the formula given below:

$$\text{Fruit set (\%)} = \frac{\text{Number of fruits set}}{\text{Total number of flowers}} \times 100$$

$$\text{Fruit drop (\%)} = \frac{\text{Number of fruits dropped}}{\text{Number of fruits set}} \times 100$$

Fruit retention (%): The fruits on the tagged branches were counted two weeks before harvesting and the fruit retention was calculated:

$$\text{Fruit retention (\%)} = \frac{\text{Number of fruits set - Number of fruits dropped}}{\text{Number of fruits set}} \times 100$$

Fruit maturity: The date on which more than 70% of fruits on the tagged branches attained 50% colour was noted as time of fruit maturity.

Fruit weight, yield, size and self-compatibility: Fruit weight was measured with the help of pan balance and fruit yield by multiplying average fruit weight with total number of fruits per tree. Fruit size was measured with the help of vernier caliper. To analyze and record the self-compatibility status of the genotypes, branches on all sides of the plum tree were tagged and some flowers were covered with muslin bags before anthesis while other flowers were kept open. The trees where the fruit set was observed on the covered flowers were labeled as self-compatible and others self-incompatible.

RESULTS AND DISCUSSION

Vegetative characteristics: The maximum tree height (5.45 m) was in genotype 'Manake Lalri' and which is statistically at par with Yellow Alubokhara (5.30 m). Minimum tree height was in 'Kala Amritsari' (2.15m) followed by 'Frontier' and 'Sharps Early'. Kumar et al (2018) also observed lower plant height in genotypes Frontier and Mariposa in the hilly regions of Himachal Pradesh. Tree girth was maximum in genotype Manake Lalri (61.12 cm) which is statistically at par with genotypes Yellow Alubokhara and Kataru Chak. Minimum tree girth was in Satluj Purple (43.10 cm) closely followed by Frontier. The mean tree volume ranged between 7.56 (m^3) and 24.44 (m^3), suchdiverse growth characteristics were also been recorded by Kumar et al (2013). The variation in tree height, tree girth and tree volume among different plum genotypes may be due to their genetic constitution and adaptability to different soil and climatic conditions (Chaurasiya and Mishra 2017). Plums are deciduous trees, hence shed their leaves at start of autumn and start growing new ones within 3 to 4 months of shedding.. Leaf fall started from 3rd week of October and continued up to 3rd week of January in different plum genotypes (Table 1). The leaf fall started earliest in genotype Satluj Purple (11 October-26 December) while Manake Lalri was last to shed its leaves (15 December to 23 January). Leaf emergence started from 2nd week of February and continued up to 3^{rdt} week of March in plum genotypes during the present studies. Thus, leaf fall and leaf emergence started early in genotypes Satluj Purple, Frontier, and Sharps Early and the period of leaf fall varied from 6 to 8 weeks whereas leaf emergence varied from 3 to 4 weeks in plum genotypes.

Start and duration of flowering and full bloom: Flowering initiated earliest in Satluj Purple (9th Feb) followed by Kala Amritsari (11th Feb), Frontier and Sharps Early (12th Feb and 13thFeb, respectively). Full bloom also commenced early in Satluj Purple (14thFeb), Kala Amritsari (17th Feb), Frontier

(17[th] Feb) and Sharps Early (19[th] Feb). The time of flower initiation depends on temperature, altitude and other environmental conditions and thus, depict some variation every year (Mahato et al 2015). The duration of flowering varies from 6 to 8 days in different plum genotypes. Minimum duration (6 days) was in genotypes Frontier, Kataru Chak,and Satluj Purple and maximum (8 days) in Yellow Alubokhara. Kour (2018) noted floral parameters and flowering characteristics of sub-tropical plum cultivars Satluj Purple, Manaka and found that Satluj Purple started flowering on 5[th]February and full bloom of Manaka and Satluj Purple lasted for 9 days. Sharma (2018) observed that the initiation of flowering in Frontier took place in 3[rd] week of February under mid hills of Himachal Pradesh whereas under the present studies the initiation in these genotypes took place in 2[nd] week of February. This difference might be due to early completion of chilling hours under sub-tropical climate of Punjab as compared to hills of Himachal Pradesh.

Fruit set, drop and retention: Fruit set in the seven plum genotypes ranged from 12.09% to 53.56 % (Table 2). Highest fruit set (53.56%) was in Sharps Early which is statistically at par with Satluj Purple and Frontier. Minimum fruit set was in Kataru Chak (12.09%) and Yellow Alubokhara (15.72%). Milatovic et al (2021) observed similar variation in final fruit set (17.7% to 49.7%) of different plum cultivars. Maximum fruit drop was in Kataru Chak (76.44%) and Manake Lalri (76.14%) which was significantly higher than all the genotypes. Minimum fruit drop was in Frontier (46.23%) and Sharps Early (47.67%). Fruit retention also varied significantly during the present studies. Fruit retention was highest in Frontier (53.77%) and Sharps Early (52.33%). Lowest fruit retention was in genotype Manake Lalri (23.85%) followed by Kataru Chak (23.56%). Saini (2020) also found lower fruit drop and higher fruit retention in Satluj Purple plum grafted on Kabul Green Gage rootstock. Higher fruit drop in Kataru Chak and Manake Lalri may be due to overbearing, thin pedicel and environmental stress.

Fruit maturity and duration of harvesting: Earliest fruit maturity was in Satluj Purple (1[st] May), followed by Kala Amritsari, Frontier (both 4[th] May) and Sharps Early (5[th] May) while duration of harvesting varied from 6 to 11 days in different plum genotypes. Minimum duration of harvesting was in Yellow Alubokhara (6 days) whereas maximum duration in Kala Amritsari (11 days) followed by Satluj Purple

Table 1. Vegetative and flowering characteristics of plum genotypes

Genotypes	T.H (m)	T.G (m)	T.V (m^3)	Period of leaf fall	Period of leaf emergence	Start of flowering	Time of full bloom	Duration of flowering
Sharps arly	3.85	49.12	17.87	20 Oct- 04 Dec	11 Feb-8 Mar	13 Feb	19 Feb	7 days
Frontier	3.50	43.87	16.43	24 Oct-10 Dec	9 Feb-5 Mar	12 Feb	17 Feb	6 days
Yellow Alubokhara	5.30	56.50	22.74	26 Oct-15 Dec	15 Feb-11 Mar	19 Feb	26 Feb	8 days
Manake Lalri	5.45	61.12	24.44	15 Dec-23 Jan	15 Feb-17 Mar	20 Feb	26 Feb	7 days
Kataru Chak	4.47	56.37	20.30	10 Dec-11 Feb	27 Feb-14 Mar	01 Mar	06 Mar	6 days
Satluj Purple	4.24	43.12	19.10	11 Oct-26 Dec	26 Feb-4 Mar	09 Feb	14 Feb	6 days
Kala Amritsari	2.15	46.27	7.56	24 Oct-5 Jan	7 Feb-6 Mar	11 Feb	17 Feb	7 days
CD (p=0.05)	0.70	10.87	1.15					

T.H: tree height, T.G: tree girth, T.V: tree volume, m: meter, m^3: meter cube

Table 2. Fruit set, drop, retention (%), maturing and harvesting time, self-compatibility and yield characteristics of plum genotypes

Genotypes	Fruit set (%)	Fruit Drop (%)	Fruit retention (%)	Time of fruit maturing	Duration of harvest	Average no. of fruits per tree	Fruit yield per tree (kg)	Self-compatibility status
Sharps early	53.56	47.67	52.33	5-12 May	8 days	1108.25	29.96	S.C
Frontier	50.23	46.23	53.77	4-12 May	9 days	1025.75	31.12	S.C
Yellow Alubokhara	15.72	54.03	45.96	25-30 May	6 days	32.00	0.47	I.C
Manake Lalri	42.29	76.14	23.85	12-20 May	9 days	4095.25	21.10	S.C
Kataru Chak	12.09	76.44	23.56	14-21 May	8 days	582.50	8.71	S.C
Satluj Purple	51.87	56.72	43.27	1-10 May	10 days	847.71	35.18	I.C
Kala Amritsari	44.63	50.13	49.86	4-14 May	11 days	3001.00	40.00	S.C
CD (p=0.05)	3.09	1.39	1.09			177.82	1.22	

Kg: kilogram, S.C: self-compatible, I.C: incompatible

(10 days). Other than genetic makeup and environment, orchard management techniques such as water, nutrients, canopy plant growth regulators also influence fruit maturity. The examination of data shows that plum genotypes begin maturing in the 1st week of May and continue through to the last week of the month under sub-tropical conditions of Punjab. On the basis of fruit maturity, these genotypes can be distinguished into 2 groups i.e early and mid-maturing. Early group consisted of genotypes which mature in the 1st fortnight of May (Satluj Purple, Kala Amritsari, Frontier and Sharps Early), mid group consisted of genotypes which mature in 2nd fortnight of May (Manake Lalri, Kataru Chak, and Yellow Alubokhara).

Fruit yield and self-compatibility status: Average number of fruits varied significantly in different plum genotypes (Table 2). The highest number of average fruits were observed in genotype Manake Lalri (4095.25) followed by Kala Amritsari (3001) which is significantly higher than all other genotypes. The genotype Yellow Alubokhara produced lowest number of fruits (32). Average fruit yield also varied significantly from one genotype to another and ranged between 0.47 kg to 40.00 kg. Kang et al (2005) also found that fruit yield in different plum genotypes varied from 0.24 kg/tree to 32 kg/tree.

Maximum fruit yield (40.0 kg) was in Kala Amritsari which was significantly higher than all other genotypes and was followed by Satluj Purple, Frontier, Sharps Early. Minimum fruit yield (0.47 kg) in Yellow Alubokhara genotype, may be attributed to the significantly low number of fruits produced per tree. Higher fruit yield in Kala Amritsari may be due to more number of fruits whereas higher fruit yield in Satluj Purple, Frontier, Sharps Early was due to higher fruit weight. Average yield per tree depends on pollination, orchard management, vegetative growth, nutrition and also the genetic makeup of the plant (Thakur et al 2023). Genotypes Frontier, Sharps Early, Manake Lalri, Kala Amritsari and Kataru Chak were self compatible in nature. These genotypes do not require any pollinizer for fruit set and are self-sufficient. This characteristic is entirely dependent on genetic constitution of the plant.

Fruit shape and its adherence to the stone: Fruits of different plum genotypes are of four shapes *viz.* round, heart, elliptic and oblate (Table 3). Three genotypes were observed having round shaped fruits (Frontier, Satluj Purple, and Kataru Chak), two with oblate shaped fruits (Yellow Alubokhara and Kala Amritsari), one with elliptic and heart shaped fruits (Manake Lalri and Sharps Early) respectively. Major characteristic exhibited by plum genotypes was clingstone as three out of seven genotypes were having this character while only two genotypes *viz.* Frontier and Kataru Chak were freestone and the other two genotypes exhibited semi-cling type characteristics (Manake Lalri and Sharps Early). Thakur et al (2023) observed clingstone and freestone characteristic of genotypes Satluj Purple and Frontier, respectively. The shape of fruit of plum genotypes Frontier was in accordance with Sundouri et al (2017) who also noted the round shaped fruits of the genotype.

Fruit weight, length and diameter: Maximum fruit weight (41.5 g) was in Satluj Purple, followed by Frontier and Sharps Early which recorded fruit weight of 31.12 g and 29.96 g respectively. Minimum fruit weight (2.57 g) was in Manake Lalri. The variations in fruit weight of different plum genotypes were due to inter-varietal differences, variation in genetic makeup, which is further governed by the sizes of fruit cells and intercellular spaces between them. The results obtained are in close conformity with the investigations conducted by Milosevic (2013) and Blazek and Pistekova (2009). Maximum fruit length (45.10 mm) and fruit diameter (41.23 mm) was in Satluj Purple and these were significantly higher than all other genotypes. It was followed by Frontier and Sharps Early with fruit size of 34.07 mm length and 32.53 mm diameter and 33.56 mm length and 30.47 mm in diameter, respectively. Minimum fruit size (6.3 mm length and 6.78 mm diameter) was in genotype Manake Lalri which is significantly

Table 3. Size, colour and fruiting characters of different plum genotypes

Genotypes	Fruit shape	Adherence to stone	Fruit weight (g)	Fruit length (mm)	Fruit diameter (mm)	Peel colour	Flesh colour
Sharps Early	Heart	Semi-cling	29.96	33.56	30.47	Red-purple	Red
Frontier	Round	Freestone	31.12	34.07	32.53	Grey-purple	Yellow-orange
Yellow Alubokhara	Oblate	Clingstone	13.21	24.25	29.12	Green yellow	Yellow
Manake Lalri	Elliptic	Semi-cling	2.57	6.34	6.78	Red-yellow	Red-yellow
Kataru Chak	Round	Freestone	11.50	20.12	21.00	Orange-yellow	Yellow
Satluj Purple	Round	Clingstone	41.50	45.10	41.23	Red-purple	Yellow-orange
Kala Amritsari	Oblate	Clingstone	13.21	21.02	23.23	Dark purple	Yellow
CD (p=0.05)			2.23	1.44	1.42		

lower than all other genotypes. The fruit weight of genotype Kala Amritsari varies from the results obtained by Kamat et al (2020) who observed that the mean weight of Kala Amritsari ranged between 19.83 and 40.10 g. Sundouri et al (2018) recorded varied results for weight, length and breadth of genotype Frontier. The differences in results may be due to nutritional and environmental variations.

Peel colour and flesh colour: Plums exhibit wide variation in colors due to differences in their genetic makeup. Plums can be classified according to different shades of three primary colors *viz.* yellow, red and purple. Genotypes Yellow Alubokhara and Manake Lalri fall under the category of yellow plums while genotypes Sharpa Early and Satluj Purple exhibited mixed shades of red and purple colour. Genotypes Satluj Purple, Frontier and Kala Amritsari have varied shades of purple. Thakur et al (2023) observed purplish black skin colour of Kala Amritsari and reddish-purple in Satluj Purple, which is similar to current studies. Maximum plum genotypes had a shade of purple peel, making it the most common peel color. Red-yellow skin color was in Manake Lalri. Distinct greenish-yellow color with orange blush and grey-purple color was observed in the peels of genotypes Yellow Alubokhara and Frontier, respectively. Yellow was the most common flesh color found in fruits of plum genotypes (Yellow Alubokhara, Kataru Chak, Kala Amritsari). The results obtained in this present study regarding peel and flesh color of genotype Frontier is similar to those reported by Sundouri et al (2017).

CONCLUSIONS

Plum genotypes Sharps Early and Frontier performed better as compared to other genotypes on the basis of growth, yield and self-compatibility status and thus can be further evaluated for cultivation under sub-tropical conditions of Punjab which would help in breaking the existing monoculture of cultivar 'Satluj Purple' in the state.

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Genetic Evaluation and Assessment of Parthenocarpic Cucumber (*Cucumis sativus* L.) Genotypes

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***Abstract*:** The genetic diversity of fourteen quantitative and qualitative traits was evaluated across thirteen parthenocarpic cucumber genotypes in the northern plains of India. Based on overall performance, the hybrids Kian, Punjab Kheera Hybrid-11, and check variety (Punjab Kheera-1) were determined to be the most promising for fruit yield per plant and several other horticultural attributes. The phenotypic coefficient of variation was higher than the genotypic coefficient of variation for traits such as the nodal position of the first female flower, the number of female flowers per node, the number of fruits per plant, and marketable yield per plant. Moderate variation was noted for days to anthesis of the first female flower, fruit length, internodal length, vine length, and total soluble solids. High heritability was observed for all traits except harvest duration. Traits such as the nodal position of the first female flower, the number of female flowers per node, fruit length, the number of fruits per plant, internodal length, and vine length exhibited high heritability coupled with high genetic advance. This indicates a predominance of additive gene action, suggesting that direct selection for these traits is advisable to enhance parthenocarpic cucumber production.

***Keywords*:** Cucumber, Genotypes, Heritability, Phenotypic, Variability

Cucumber (*Cucumis sativus* L.), a key horticultural crop belonging to the Cucurbitaceae family and can be grown in both summer and rainy seasons in an open environment (Kaur et al 2023). However, their productivity may be low due to various abiotic stresses like low temperatures and unpredictable weather, as well as biotic stresses such as red pumpkin beetles, fruit flies, and downy or powdery mildew, therefore cultivating cucumbers in protected environments can be a more profitable option (Dhillon et al 2017) as protected farming can minimize both biotic and abiotic stresses (Reddy et al 2023). Genetic variability is essential in base population for the successful crop improvement for the yield and its associated characters (Luther et al 2024). The accomplishment of crop enhancement program be contingent upon the degree of variability present in the inhabitants (Meena and Bahadur 2014). The development of promising genotypes largely depends on the extent of genetic variability present for the desired traits (Singh et al 2022). Key biometric tools for assessing genetic variability include the genotypic coefficient of variation (GCV), phenotypic coefficient of variation (PCV), heritability, and genetic advance. Most of the farmers use private sector hybrids which are available in the market, although the cost of the seeds is very expensive owing to that most of the farmers not afford them. Therefore, it is necessary to create public sector varieties/hybrids suitable for cultivation under protected cultivation. This study aims to calculate the degree of variance among horticultural traits and to identify the most promising hybrid(s)/varietie(s) of parthenocarpic cucumber.

MATERIAL AND METHODS

The experiment was laid out during the spring summer season 2022-2023, by evaluating the thirteen genotypes with three replications with RBD design at Vegetable Research Farm, Department of Agriculture, Khalsa College, Amritsar (Table 1). Nursery was sown in soilless media (cocopeat, perlite and vermiculite in 3:1:1, respectively) and transplanting was done at 2-3 true leaf stage in natural ventilated polyhouse (250 m^2). In each replication 20 plants of each hybrid were planted at a spacing of 90 cm x 30 cm. Through the crop growing season, irrigation, fertigation, earthing up, fertilizing, stacking and crop protection measures are implemented as part of the PAU, Ludhiana (Package of practices 2021). The observations were made on the following characteristics: days taken to first female flower anthesis, first female flower nodal location, number of female flowers per node, days taken to first fruit harvest, fruit length, fruit girth, fruit weight, number of fruits per plant, marketable yield per plant, harvest duration, internodal length, vine length and total soluble solids. Using the analysis of variance, trait were analysed. The GCV, PCV, heritability, and genetic advance were calculated using the WINDOSTAT software program.

RESULTS AND DISCUSSION

Growth parameters: One of the cucumber's most desired qualities is its earliness, since early in the season, market prices are typically higher. Significant variations in the days to first picking were seen among the genotypes studied (Table 2). Hybrid Kian took the fewest days to anthesis of the first female flower, but three genotypes, PPC-6, Punjab kheera-1, and KPCH-1, were statistically at par this was due to the relation between appropriate climatic conditions and genotype genes. Similar observations noted in cucumber for minimum days taken to anthesis of first female flower by Shaju et al (2020) in variety Kohinoor (36.09 days) and Tripathi et al (2021) in genotype BRPCU-1 (24.06 days).

PPC-2 was produced the first female flower at the lowest node, while other genotypes PPC-3, PKH-11 and Kian were statistically comparable (Table 2). For number of female flowers per node line KCA-PC-2 was d superior whereas KCA-PC-3, KCA-PC-1 and Apsara were statistically at par. as Choudhari et al (2016) observed minimum days to anthesis of first female flower in cucumber variety RS-03602833 (25.00 days) and Mehta and Sharma (2020) had maximum number of female flowers per node in cucumber variety PPC-3 (2.38). The early maturing genotype is crucial for securing early markets, as hybrid Kian took the least number of days to first harvest and matured the earliest, whereas PPC-6, Punjab Kheera-1, and KPCH-1 were statistically at par. This was due to the higher photosynthesis in these genotypes which stimulates the initiation of flowers.

Table 1. Parthenocarpic cucumber genotypes used in study and their sources

Genotypes	Source
Punjab Kheera-1 (Standard check)	Punjab Agricultural University (PAU)
Punjab Kheera Hybrid-11 (PKH-11)	Punjab Agricultural University (PAU)
Kerala Parthenocarpic Cucumber Hybrid-1 (KPCH-1)	Kerala Agricultural University (KAU)
Kian	Nunhems Seeds Pvt. Ltd.
Adiva	Tropica Seeds Pvt. Ltd.
Apsara	Acsen Hyveg Pvt. Ltd.
Yamchu	Takoyama Plant Science
Pusa Parthenocarpic Cucumber-6 (PPC-6)	Indian Agricultural Research Institute (IARI)
Pant Parthenocarpic Cucumber-2 (PPC-2)	G.B. Pant University of Agriculture. Pantnagar
Pant Parthenocarpic Cucumber-3 (PPC-3)	G.B. Pant University of Agriculture. Pantnagar
KCA-PC-1	Khalsa College, Amritsar
KCA-PC-2	Khalsa College, Amritsar
KCA-PC-3	Khalsa College, Amritsar

Table 2. Mean performance of parthenocarpic cucumber genotypes for growth and yield traits

Genotypes	Days to anthesis of first female flower	Nodal position of first female flower	Number of female flowers per node	Days taken to first fruit harvest (days)	Fruit length (cm)	Fruit girth (cm)
Adiva	25.00	3.00	1.89	40.67	14.00	12.50
PPC-2	25.37	2.78	1.71	43.00	16.00	13.77
PKH-11	24.33	2.93	1.12	40.00	15.33	12.00
KCA-PC-1	32.00	4.19	3.08	48.67	16.33	12.33
Apsara	25.23	3.63	3.00	42.67	16.17	13.17
KCA-PC-2	27.33	4.50	3.40	45.67	13.33	12.17
KPCH-1	24.00	4.09	2.07	39.67	14.83	11.83
KCA-PC-3	32.33	6.25	3.29	48.67	15.67	13.23
Yamchu	25.67	4.39	2.82	44.67	19.67	12.27
PPC-3	31.33	3.17	1.30	47.00	20.83	12.83
Kian	21.67	2.93	1.14	37.00	14.50	11.07
PPC-6	23.33	4.60	1.86	38.67	13.50	12.20
Punjab Kheera-1	23.67	3.23	1.91	39.00	14.17	11.90
CD (p=0.05)	2.20	0.38	0.15	3.64	0.90	0.48

Patra et al (2023) having similar results as cucumber hybrid Aviva took minimum days (52.60) to harvest.

Marketable yield and consumer preference are directly impacted by fruit girth, length and weight. PPC-3 outperformed for fruit length, whereas Yamchu and KCA-PC-1 were statistically at par (Table 3). Fruit girth was maximum in PPC-2 while genotypes viz., KCA-PC-3, Apsara and Kian were statistically at par. For fruit weight, Apsara had the highest weight from all the hybrids, whereas other genotypes such as Yamchu, PPC-2, and PPC-3 were statistically comparable. Fruit length, girth and weight was higher in these lines due to genetic makeup of the genotype as well as the proper supply of nutrition's during the growth of the fruit. The commercial viability of a variety is determined by its yield and number of fruits produced per plant. Among all hybrids, hybrid PKH-11 produced the most fruits per plant, substantially more than the other genotypes but statistically at par with the genotypes Punjab kheera-1, Kian and KCA-PC-2. But hybrid Kian had maximum yield per plant which was statistically at par with variety (Punjab Keera-1), hybrid (PKH-11 and Apsara). Kumar et al (2024) demonstrated maximum number or fruits (30.47) and yield per vine (3.87 kg) in cucumber genotype BRPCU-7.

Prolonged availability of marketable fruits was found in Kian, which was statistically comparable to other genotypes Punjab Kheera-1, KCA-PC-2 and PKH-11. Shorter internodal length was also in hybrid Kian, whereas genotype PPC-6, hybrid Apsara and variety Punjab kheera-1 were statistically at par due to the genetic makeup of cultivars. For plant height KCA-PC-2 was found to be much taller than the other genotypes, but Yamchu, PPC-2 and Apsara, statistically equal. This might be due to certain genes that control and express varietal qualities, such as height, shortness, and other physical features, in response to the growing environment. Dhillon et al (2017) has similar findings had maximum harvest duration (54.67 days), inter-nodal length (9.86 cm) and vine length (2.42 m) in hybrid Kian. The crucial component of fresh cucumber ingestion is total soluble solids, hybrid PKH-11 had the highest total soluble solids, although it was at par with Adiva, hybrid Yamchu, and variety PPC-3 (Table 3). Dhall (2019) had maximum TSS (2.60˚Brix) in variety Punjab Kheera-1.

Genetic variability: Higher values of both phenotypic coefficient of variation (PCV) and genotypic coefficient of variation (GCV) were observed nodal position of the first female flower, the number of female flowers per node and the number of fruits per plant (Table 4). In contrast, marketable yield per plant showed a significant GCV but not PCV, indicating that environmental factors have minimal influence on these traits. As a result, direct selection could be effectively applied to these traits in early segregating populations. Ahirwar and Singh (2018) and Patra et al (2023) showed similar trends in cucumbers with regard to PCV and GCV for number of fruits per plant, nodal position of the first female flower and marketable yield per plant.

Moderate values of both phenotypic coefficient PCV and GCV were observed for traits internodal length, vine length, and total soluble solids. Additionally, PCV was moderate for the number of fruits per plant, days to first fruit harvest and harvest duration. In contrast, GCV was moderate only for the

Table 3. Mean performance of parthenocarpic cucumber genotypes for growth, yield and quality traits

Genotypes	Fruit weight (gm)	Number of fruits per plant	Marketable yield per plant (kg)	Harvest duration (days)	Internodal length (cm)	Vine length (m)	Total soluble solids (˚Brix)
Adiva	144.69	16.10	2.33	54.00	10.23	3.87	3.60
PPC-2	155.13	13.97	2.16	50.00	12.21	3.26	3.03
PKH-11	118.64	26.56	3.15	57.33	10.15	4.06	3.90
KCA-PC-1	149.14	11.76	1.75	50.00	10.19	3.46	2.64
Apsara	169.57	17.79	3.01	56.33	9.25	3.32	2.81
KCA-PC-2	134.71	20.08	2.70	57.67	10.18	4.34	2.52
KPCH-1	148.28	17.23	2.55	54.33	10.90	4.18	2.71
KCA-PC-3	148.92	16.26	2.42	55.67	12.40	4.26	2.91
Yamchu	162.17	11.77	1.91	55.33	12.69	3.16	3.46
PPC-3	150.22	13.71	2.06	51.33	13.98	4.25	3.23
Kian	139.77	24.18	3.37	58.67	7.64	4.20	3.10
PPC-6	141.18	20.03	2.83	55.67	8.89	3.39	3.04
Punjab Kheera-1	131.44	24.70	3.25	58.00	9.70	2.91	2.83
CD (p=0.05)	5.17	1.15	0.13	3.21	0.23	0.32	0.33

days to anthesis of the first female flower and total soluble solids, indicating limited variation among the genotypes. Mehta and Sharma (2020) also reported moderate estimates of PCV and GCV in cucumber for the days taken to anthesis of the first female flower, vine length and internodal length. Low values of PCV and GCV were observed for fruit girth, fruit weight and harvest duration, indicating minimal genetic variation. These traits may not require improvement and can be effectively utilized in hybridization programs. Similar trend for PCV and GCV in cucumber observed for harvest duration and fruit weight (Tripathi et al 2021).

Heritability: The high heritability estimates were for traits such as internodal length, the number of female flowers per node, number of fruits per plant, marketable yield per plant, nodal position of the first female flower, fruit weight, fruit length, days to anthesis of the first female flower, vine length, and fruit girth (Table 4). Similar patterns were observed by Singh and Dhillon (2022) in parthenocarpic cucumbers, with the highest heritability for internodal length and number of female flowers per node . Moderate heritability was observed for days taken to first fruit harvest, total soluble solids and harvest duration. Similar results were also noted by Kumar et al. (2024) in cucumber for harvest duration . High broad-sense heritability indicates that a significant portion of the phenotypic variance is due to genotypic variance for all traits, except for harvest duration, which had the lowest heritability estimate. Traits with high heritability are less influenced by environmental factors, making selection based on phenotypic performance more reliable.

Genetic advance: The high genetic advance (% of mean) was observed for traits such as the number of female flowers per node, the number of fruits per plant, the nodal position of the first female flower, marketable yield per plant, internodal length, fruit length, and vine length (Table 4). Comparable evidence of higher genetic advancement in cucumber reported by Singh et al(2017) for marketable yield per plant and vine length .Moderate genetic advance (GA) was observed for the traits such as days to anthesis of the first female flower, total soluble solids, fruit weight and days to first fruit harvest, whereas low genetic advance was observed for fruit girth and harvest duration. Kumar et al (2024) also had moderate genetic advance for days to anthesis of the first female flower and lower for harvest duration .

Higher genetic advancement and heritability were observed for number of female flowers per node, nodal position first female flower's nodal position, number of fruits per plant, fruit length, marketable yield per plant, vine length and internodal length, which shown the importance of additive gene action for these traits inheritance and suggested that phenotypic selection may be use to further improve them. These findings were consistent with the results of Mishra et al (2020), Bisht et al (2022) and Kumar et al (2024). High GCV, PCV, heritability along with high estimates of genetic advance was verified for nodal position of first female flower, number of female flowers per node, number of fruits per plant and marketable yield per plant. Majority of additive gene action which recommended that these traits can be improved through direct selection (Tripathi et al 2021 , Bisht et al 2022).

Table 4. Measures of variability parameters (GCV, PCV, heritability and genetic advance) for different characters in parthenocarpic cucumber genotypes

Traits	Grand mean	Phenotypic coefficient of variation (%)	Genotypic coefficient of variation (%)	Heritability (%)	Genetic advance value % mean
Days taken to anthesis of first female flower	26.25	13.88	12.95	87.09	24.91
Nodal position of first female flower	3.82	26.24	25.56	94.83	51.27
Number of female flowers per node	2.19	37.46	37.22	98.73	76.19
Days taken to first fruit harvest	42.71	10.09	8.72	74.74	15.54
Fruit length (cm)	15.71	14.59	14.18	94.37	28.37
Fruit girth (cm)	12.41	5.99	5.52	85.10	10.50
Fruit weight (g)	145.68	9.22	8.98	94.77	18.01
Number of fruits per plant	18	27.21	26.94	98.00	54.94
Marketable yield per plant (kg)	2.57	20.61	20.37	97.64	41.46
Harvest duration (days)	54.94	6.03	4.92	66.71	8.29
Internodal length (cm)	10.65	16.47	16.40	99.21	33.67
Vine length (m)	3.74	14.10	13.11	86.42	25.10
Total soluble solids (˚Brix)	3.01	14.28	12.42	75.60	22.25

CONCLUSION

Parthenocarpic cucumber hybrids (Kian and Punjab Kheera Hybrid-11 and Punjab Kheera-1) and varieties (Pusa Parthenocarpic Cucumber-6 and Pant Parthenocarpic Cucumber-3) were superior for growth, yield and quality attributes. PCV and GCV estimates were recorded as high and moderate for days to anthesis of the first female flower, nodal position of the first female flower, number of female flowers per node, number of fruits per plant, internodal length, vine length, and total soluble solids. This indicates the presence of variability, providing significant opportunities for improvement through hybridization or selection. Additionally, high heritability combined with high genetic advance was observed for the nodal position of the first female flower, number of female flowers per node, fruit length, number of fruits per plant, marketable yield per plant, internodal length, and vine length. This suggests that additive gene action plays a key role in the inheritance of these traits, allowing for further improvement through phenotypic selection.

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Impact of Temperature on Survival and Fecundity of *Spodoptera litura* on Capsicum

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Abstract: The tobacco caterpillar, *Spodoptera litura* (Fab.), is a pervasive pest affecting numerous plant species. This study investigates the life fertility parameters of *S. litura* on capsicum under varying temperatures to enhance pest management strategies. With experiments conducted at the Dr. Y.S. Parmar University of Horticulture and Forestry, India, this research aims to elucidate the impact of temperature on the reproductive potential of *S. litura*. By analyzing key fertility parameters such as gross reproductive rate (GRR), net reproductive rate (R0), and intrinsic rate of increase (rm). The study assesses the optimal temperature conditions for *S. litura* reproduction. The optimal conditions for reproduction occur at 25°C, but the highest intrinsic rate of increase was recorded at 35°C, indicating accelerated population growth under higher temperatures despite a reduction in individual fecundity. These insights contribute to more precise pest control strategies by highlighting temperature's role in *S. litura* population dynamics, thereby improving Integrated Pest Management (IPM) interventions.

Keywords: Tobacco caterpillar, Life fertility parameters, Population dynamics, Insect ecology

The tobacco caterpillar, *Spodoptera litura* (Fabricius), is a highly polyphagous pest known to damage a wide range of crops, including vegetables, grains, and oilseeds, making it one of the most economically significant agricultural pests worldwide (Zakria et al 2022), affecting over 290 plant species across 99 families (Wu et al 2004). Its adaptability to various environments and host plants, coupled with its high reproductive potential, has led to increased reliance on chemical pesticides for management (Sharma et al 2018). However, the excessive use of chemical controls has resulted in pest resistance and negative environmental impacts, emphasizing the need for integrated pest management (IPM) strategies (Brar and Sharma 2017, Sharma et al 2024).

Temperature is a critical abiotic factor influencing the life cycle of insects, affecting their development, survival, and reproduction. As ectothermic organisms, *S. litura* is particularly sensitive to temperature variations, which can significantly alter its biological performance (Karmakar and Pal 2017). Studies have shown that temperature affects key life history traits such as growth rates, developmental thresholds, and fecundity (Rao and Prasad 2020, Zhong et al 2024). Elevated temperatures can enhance metabolic rates, leading to increased food consumption and faster development, while also influencing the insect's interaction with natural enemies (Islam et al 2022, Yi et al 2020). Research has demonstrated that specific temperature ranges can optimize the development and reproductive success of *S. litura*. For instance, optimal conditions promote higher survival rates and fecundity, while extreme temperatures may negatively impact these parameters (Duraimurugan 2018, Sharma et al 2018). Moreover, temperature fluctuations can influence the dynamics of pest populations and their associated predators, further complicating pest management strategies (Zhu et al 2017).

Understanding the ecological and physiological responses of *S. litura* to temperature is vital for developing effective pest management practices. Life table studies serve as valuable tools in this regard, providing insights into the dynamics of pest populations under varying environmental conditions. They allow for the evaluation of demographic parameters such as age-specific survival rates, fecundity, and population growth rates, which are essential for modeling pest behavior and predicting outbreaks (Chi and Su 2006). In light of the growing concerns surrounding climate change and its impact on agricultural systems, this study aims to examine the influence of temperature on the survival and fecundity of *S. litura* when reared on capsicum (*Capsicum* spp.). By constructing life fertility tables for *S. litura* under different temperature regimes, seek to elucidate the relationship between temperature and pest dynamics, thereby informing better management strategies to mitigate the impacts of this pest on capsicum cultivation.

MATERIAL AND METHODS

The investigations on "Studies to construct life fertility tables of *Spodoptera litura* on capsicum" were conducted Dr. Y.S. Parmar University of Horticulture and Forestry, Nauni, Solan, HP, India. The host plants used in this study included capsicum. (*var.* Solan Bharpur). Seed beds were prepared with a 1:1 mixture of soil and farmyard manure, and eight-week-old seedlings with 3 to 4 leaves were transplanted into the field, following standard cultural practices without insecticide application. Fresh leaves from these plants were used in the study. The culture of *S. litura* was established by collecting larvae from polyhouses and open fields at the Entomological Research Farm and Vegetable Research Farm of the university. The larvae were reared in plastic jars (15 cm × 21 cm) under laboratory conditions with fresh castor leaves, which were changed twice daily. To prevent microbial infections, castor leaves were washed with dilute potassium permanganate solution, rinsed with water, and air-dried. The jars were thoroughly cleaned with detergent and air-dried. Larvae were reared for at least two generations on the same host plant species. Mature larvae ready for pupation were transferred to jars with 5 cm of moist soil to facilitate pupation. Pupae were collected and transferred to other jars for adult emergence. Newly emerged adults were paired and kept in jars for mating and egg laying, with a cotton wick soaked in 10% sucrose solution for adult feeding. The inner surfaces of the containers were lined with filter paper for egg laying. Eggs were collected every 12 hours and used in experiments.

Life fertility studies of *S. litura* were conducted on capsicum at 20, 25, 30 and 35°C. After rearing the test insect for at least one generation to negate the effects of the previous host, data on developmental stages, mortality and fertility parameters (preoviposition period, oviposition period, postoviposition period and daily egg production) were recorded. Fertility parameters, including gross reproductive rate (GRR), net reproductive rate (R0), approximate generation time (TC), innate capacity for natural increase (rc), true intrinsic rate of increase (rm), true generation time (T), finite rate of natural increase (λ), and doubling time (DT), were calculated according to methods described by Birch (1948), Howe (1953), and Watson (1964). Repeated estimates of each fertility parameter were obtained using the Jackknife procedure (Meyer et al 1986), following the methodology described by Maia et al (2000), ensuring reliable and accurate results. These fertility tables provided insights into the influence of temperature on the survival and fecundity of *S. litura*, contributing to the development of pest management strategies.

RESULTS AND DISCUSSION

Age-specific survival and fecundity parameters of *S. litura* on capsicum at different temperatures: The survival and fecundity of *S. litura* on capsicum were influenced significantly by temperature. At 20°C, the survival rate was initially high but gradually declined, with all females dying by the 73rd day (Fig. 1). Similar trend was observed at 25°C, where survival declined more rapidly, with all adults dying by the 56th day (Fig. 2). At 30°C and 35°C, the survival period was further shortened, with all adults dying by the 40^{th} (Fig. 3) and 24^{th} (Fig. 4) days, respectively.

The age-specific fecundity of *S. litura* on capsicum varied with temperature. At 20°C, egg laying began on the 55th day, peaking at 111.17 eggs per female, then fluctuating slightly before declining to 19.19 by the 64th day, with no eggs laid beyond the 65th day (Fig. 1). At 25°C, egg-laying started earlier and peaked at higher numbers, with a rapid decline afterward (Fig. 2). At 30°C and 35°C, peak egg production occurred even earlier, with a more condensed egg-laying period and a faster decline in fecundity (Fig. 3 and 4).

Survival rates declined more rapidly at higher temperatures, with cooler conditions at 20°C prolonging the life span. Fecundity patterns showed that peak egg laying occurred earlier and in higher numbers as temperature increased, but the duration of egg-laying was shorter, indicating a more condensed reproductive phase in warmer conditions. Population dynamics indicated that the intrinsic rate of increase (rm) and finite rate of increase (λ) were higher at elevated temperatures, leading to faster population growth. However, the net reproductive rate (R0) and gross reproductive rate (GRR) peaked at 25°C, suggesting that this temperature provides optimal conditions for the reproductive success of *S. litura.*

Fertility parameters of *Spodoptera litura* on capsicum at different temperatures: The fertility parameters of *S. litura* on capsicum exhibited significant variations across different temperatures (Table 1). At 25°C, *S. litura* showed the highest reproductive output, with the greatest gross reproductive rate (GRR) and net reproductive rate (R0), indicating that this temperature provides optimal conditions for reproduction. In contrast, the lowest GRR and R0 were recorded at 35°C, suggesting that higher temperatures negatively impact reproductive potential. Both the approximate generation time (Tc) and true generation time (T) decreased with increasing temperatures. At higher temperatures, such as 35°C, the developmental and reproductive cycles were considerably accelerated, leading to faster population turnover compared to cooler conditions (Table 1). The intrinsic rate of natural increase (rm) and innate capacity for increase (rc) also showed a positive correlation with temperature, peaking at 35°C, which suggests a significant boost in reproductive efficiency at higher temperatures. The finite rate of natural increase (λ) declined with rising temperatures, whereas the doubling time (DT) shortened, indicating a more rapid population growth at warmer temperatures. Despite lower individual fecundity at higher temperatures, the overall population growth was

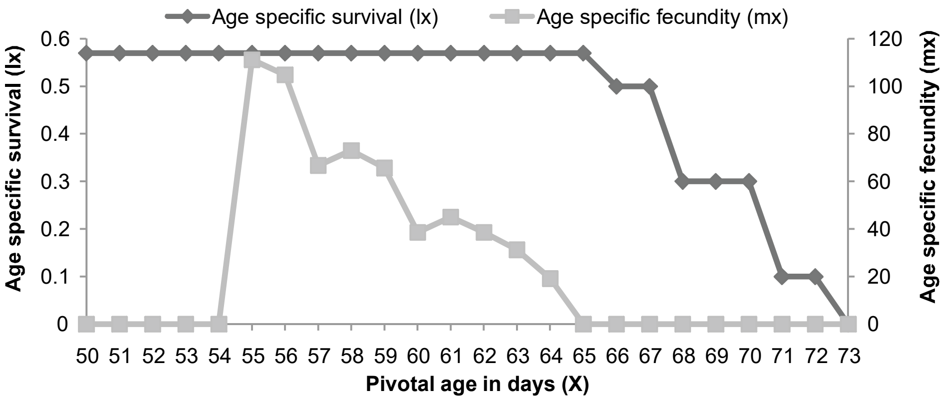

Fig. 1. Daily age-specific survival and age-specific fecundity of *S. litura* on capsicum at 20˚C

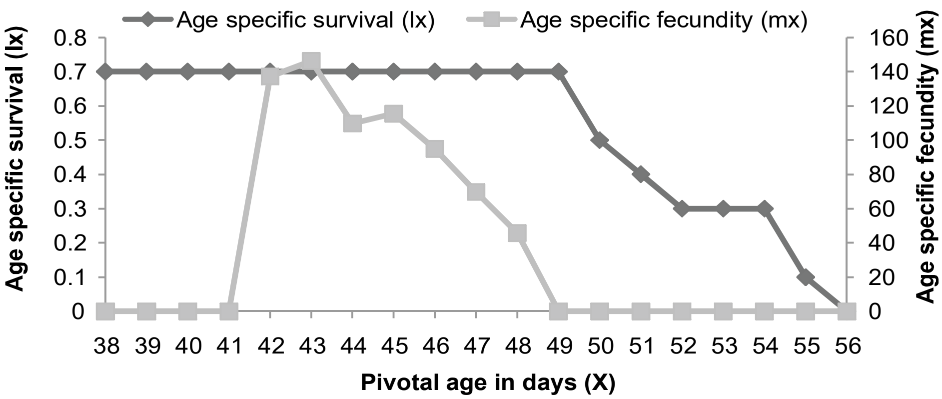

Fig. 2. Daily age-specific survival and age-specific fecundity of *Spodoptera litura* on capsicum at 25°C

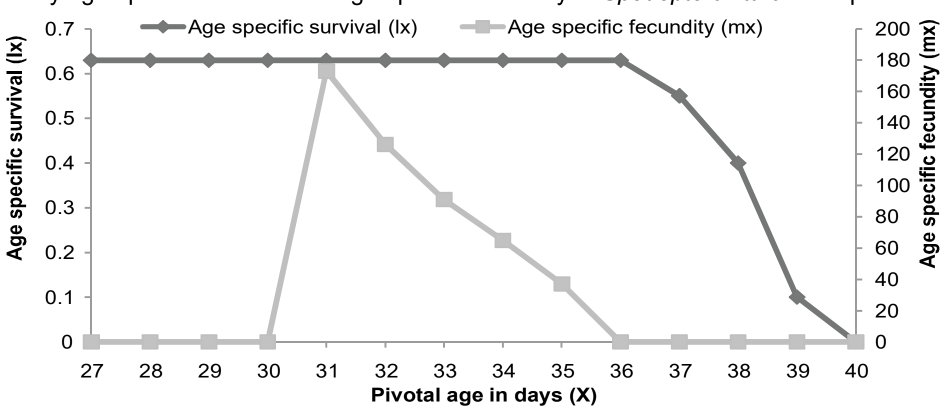

Fig. 3. Daily age-specific survival and age-specific fecundity of *Spodoptera litura* on capsicum at 30°C

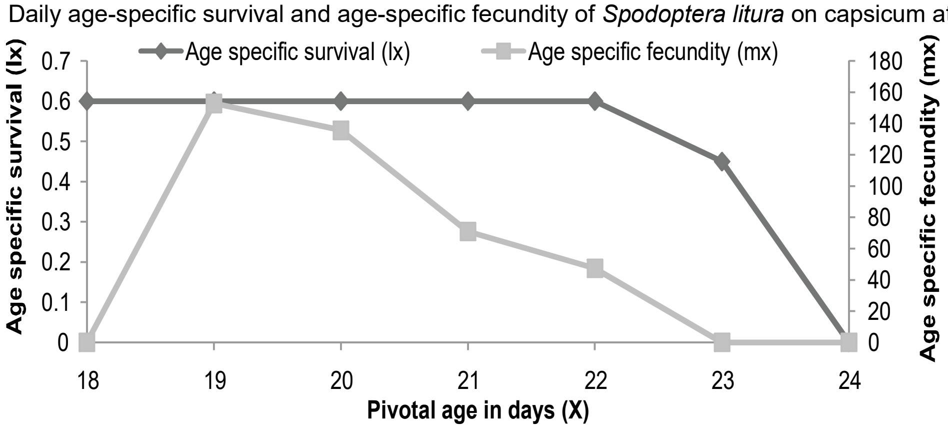

Fig. 4. Daily age-specific survival and age-specific fecundity of *Spodoptera litura* on capsicum at 35°C

accelerated due to shorter generation times (Table 1). The weekly multiplication rate (WM) also increased with temperature, showing a more rapid population expansion at 35°C.

Fertility parameters of *S. litura* on capsicum: Gross reproductive rate (GRR) was significantly higher (718.86 female eggs per female) at 25°C. It was followed by at 20 and 30°C. GRR was significantly lower (406.69 female eggs per female) at 35°C. The net reproductive rate (R_0) also followed the same trend as GRR. R_0 was significantly higher (503.2 female eggs per female) at 25°C followed by 20 and 30°C, respectively. R_0 was significantly lower (244.02 female eggs per female) at 35°C. The approximate generation time (Tc) was longest at 20°C, with shorter durations at 25°C and 30°C, and the shortest at 35°C. In contrast, the intrinsic rate of natural increase (rm) was significantly higher at 35°C, indicating rapid population growth under warmer conditions. The true generation time (T) was longest at 20°C and decreased with increasing temperature. The weekly multiplication rate (WM) was highest at 35°C, suggesting potential for rapid population expansion, while the finite rate of natural increase (λ) was significantly greater at 20°C. The doubling time (DT) was also longer at 20°C, decreasing with higher temperatures.Bharathi et al. (2008) observed similar findings on different tobacco cultivars. Similarly, Farahani et al. (2011) noted that the mean duration of pupae for *S. eridania* was greater than for *S. exigua* on different soybean cultivars. Contrasting results were obtained by Patil et al. (2014, 2015) on tobacco, highlighting variability in reproductive potential and generation periods across studies. Supriya et al. (2018) reported that *S. litura's* life parameters were negatively affected by Bt-II hybrids, indicating the impact of host plant resistance on pest population dynamics.

In this study, the age-specific survival and fecundity parameters of *S. litura* on capsicum were analyzed at four different temperatures (20°C, 25°C, 30°C and 35°C). The results demonstrated significant variations in survival and reproductive output across temperatures. Survival rates declined more rapidly at higher temperatures, with the coolest condition (20°C) prolonging the lifespan of the moths. Fecundity patterns showed that peak egg laying occurred earlier and in higher numbers as temperature increased, but the duration of egg-laying was shorter, indicating a more condensed reproductive phase in warmer conditions. The intrinsic rate of increase (r_m) and finite rate of increase (λ) were higher at elevated temperatures, leading to faster population growth. However, the net reproductive rate (R_0) and gross reproductive rate (GRR) peaked at 25°C, suggesting this temperature provides optimal conditions for the reproductive success of *S. litura*. The lowest GRR and (R0) were observed at 35°C, indicating that higher temperatures may adversely affect the reproductive potential of the species. The approximate generation time (Tc) and true generation time (T) decreased with increasing temperature, reflecting accelerated development and reproductive cycles at higher temperatures, which enable faster population turnover. Both the innate capacity for increase (r_c) and the intrinsic rate of natural increase (r_m) showed a positive correlation with temperature, indicating that higher temperatures substantially boost the reproductive efficiency and population growth rate of *S. litura*.

The finite rate of natural increase (λ) was highest at 20°C and lowest at 35°C, while the doubling time (DT) decreased with rising temperature, suggesting rapid population growth under warmer conditions despite reduced individual fecundity. The weekly multiplication rate (WM) also increased with temperature, underscoring the potential for rapid population expansion of *S. litura* in warmer climates. The results align with previous studies but also highlight the importance of temperature in influencing fertility parameters and developmental periods. Feeding on different plant parts can also cause variations in fertility parameters. The intrinsic rate of natural increase (r_m) is a critical value for determining the

Table 1. Fertility parameters of *Spodoptera litura* on capsicum at different temperatures

Parameter	Unit	20°C	25°C	30°C	35°C
Gross reproductive rate (GRR)	Female eggs/female	594.130	718.860	492.110	406.690
Net reproductive rate (R_0)	Female progeny/female	338.650	503.200	310.030	244.020
Approximate generation time (T_c)	Days	58.160	44.380	32.320	20.030
The innate capacity for increase (r_c)	Females/female/day	0.038	0.061	0.077	0.119
Intrinsic rate of natural increase (r_m)	Females/female/day	0.101	0.141	0.178	0.276
True generation time (T)	Days	25.090	19.170	13.970	8.640
Weekly multiplication rate (WM)	Folds	2.020	2.680	3.480	6.920
Finite rate of natural increase (λ)	Females/day	2.290	1.960	1.720	1.290
Doubling time (DT)	Days	2.980	2.140	1.690	1.090

temperature at which population growth is most favorable. The highest (r_m) was observed at 35°C, indicating this temperature is optimal for the reproduction of *S. litura*, leading to rapid population proliferation. However, the optimal reproductive output and growth rates were observed at 25°C, suggesting this temperature provides the best overall conditions for the reproductive success of *S. litura* on capsicum.

These findings can be used to predict *S. litura* population dynamics at different temperatures under field conditions. While many models, such as the Lotka-Volterra and Nicholson-Bailey models, use (r_m) as a key parameter, the accuracy of these models can be limited by temperature fluctuations in the field. The present study, conducted at various constant temperatures, provides a more comprehensive understanding of *S. litura* population dynamics, offering a rational and predictive basis for pest control under varying environmental conditions.

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Mutualistic Interaction of Lycaenids (Lycaenidae: Lepidoptera) with Ants and their Behavioural Response to the Environment

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Abstract: A maiden survey was conducted to ascertain the lycaenid larva associated with ant species and their coloration change, mud puddling behaviour, wing position, host plants, pollination beneficiary and nectar yielding plant species for lycaenid butterflies. Two aspects of the interactions between the larva of the *Euchrysops cnejus* and the ant, *Componotus compressus* were studied in the laboratory. Lycaenids showed their strong mutualistic behaviour with ants for their survival in the environment by benefitting each other. The larval response in delivering the honey dew droplets is proportional to the degree of ants attended. Colouration change revealed that there were two forms *viz*., WSF and DSF differentiated with markings and spots. The dry season form (DSF) of butterflies was found with markings which were light and a smaller number of spots present on the underside. Places near to water bodies or damp area was preferred by the lycaenids for mud puddling, only males undertake mud puddling in the damp area because they absorb essential elements such as sodium that have been lost during copulation in the form of sperms. Out of 45 species of lycaenid, butterflies recorded in the study area were found with WF, WS, WUHO and WUA position during rest and foraging on flowers but majority of species were found with wing upright and adpressed position at rest. Totally 64 plant species were observed as host plants of lycaenids in which Fabaceae, Rhamnaceae and Combretaceae were most preferred. Out of 24 plant species, Verbanaceace plants was most benefitted by pollination service of lycaenids and they were well attracted to yellow, white and red colour. Most of the lycaenid butterfly species were depend on *Zizyphus* spp., *Tridox procumbens, Celosia argentea, Saraca asoca, Parthenium hysterophorus* and *Bidens pilosa* for their nectar food in the study area out of 30 plant species recorded. Hence, lycaenids are playing a diversified role in the environment for their survival and involves in maintaining the health of environment by their pollination service.

Keywords: *Euchrysops cnejus,* Colouractional change, Host plants, Mud puddling, Pollination beneficiary

Butterflies are colourful and scaled winged insects of the order Lepidoptera of class Insecta. Butterflies are an indicator species which responds rapidly to environmental and land use changes and have been recognized as ecological indicators in diverse ecosystems around the world (Ekroos et al 2013, Stuhldrehera and Fartmann 2018). More than 18,000 butterfly species are known, and 90 % of these species are distributed in tropical areas (Bonebrake et al 2019). However, tropical butterfly diversity is threatened by habitat loss and global climate change (Jain et al 2017, Kirubaharan et al 2022). Butterflies perform important ecological functions, such as pollinating many plant species, and are thus highly valuable from a conservation perspective (Santos et al 2020). Devi et al (2021) reported that the presence of *Senna siamea* attracts the *Catopsilia pyranthe* butterfly which is commonly found along the roadsides in semi-urban areas. Arya et al (2020) observed that 85.92% male and 14.08 % female butterflies were feeding at various sites as puddles, moist soil, mammalian dung and algal mats. But the most unique aspect of this group is that caterpillars of several species share a very special relationship with ants and because of this particular feature caterpillars of those species have specialized secretory organs or glands to attract and reward and in return for the protection that they receive from the ants. The degree of ants attendance to caterpillars varies in different species (Kehimkar 2008). One of the most interesting facts that the early stages of many of these butterflies their association with ants who protect them from their many insect enemies in return for the sweet juice they can produce. The ants obtain the juice by gently stroking the hinder part of the caterpillar's body with their antennae causing small drops of a sweet liquid to exude from the mouth like opening in segment 11.The male lycaenid bask with their wings spread out and the upper surfaces of their wings facing the sun. The females also do so, but spend a lot of their time in finding suitable larval host plants as well. Further, he found that butterflies feed on a variety of resources. Many of them were lycaenid butterflies *viz.,* grass blues, pea blue and ceruleans, visit flowers. The majority of males were found visiting flowers and of settling on damp patches to suck up moisture, but the females do not usually have these habits and fly in the open keeping more to the jungles and busying themselves with searching for the foodstuff on which to lay their eggs. Seasonal variation occurs in a number of species, change of color and markings sometimes being very pronounced. The shape of the wings, however, seldom alters. Keeping the above in view, the following research work was carried out.

MATERIAL AND METHODS

An intensive survey was made during 2017-2018 to record the behavioral response of lycaenid butterflies in the following districts of Tamil Nadu. There were 12 districts selected, three each from east, west, north and southern parts of Tamil Nadu are given below. In each district three localities were randomly selected based on their flora and fauna suitable for butterflies. The survey area covered the localities with plains, barren lands, cropped area, hilly tract and forest covers.

Effect of ant attendance on lycaenid larval behavior and honey dew secretion: To investigate the honeydew secretion and the droplet numbers due to the stimulation of attending ant species the experiment was carried out in the laboratory. Fourth instar larvae of *E. cnejus* were collected and three treatments with different numbers of attending ants were setup. In the first treatment, a single ant was allowed to access the larva. Two ants were allowed to access the larva in second treatment. In all the three treatments, ant attending the larval droplet (honeydew) numbers was observed for every 20 minutes. The larval response to stimulated attacks of the ants was observed every five minutes period and the numbers of droplet released were counted. The interaction was observed through a Carl Zeiss Stemi DV_4 Stereomicroscope and every number of ants that touched the larva was counted to give information about the number of ants directly attending to the larva.

Colourational change of lycaenid butterflies: The lycaenid butterfly species bear a very different appearance at different seasons of the year. The change in climate and altered condition of the foodstuff producing different forms in markings and colour. The colour changes in the lycaenids were also observed from the study area while under take a survey in different seasons of the study period.

Mud puddling and wing position of lycaenids: The mud puddling behavior of lycaenid butterflies on moist substance like wet soil, bird-dropping and damp soil patches in different places of hills and plain areas were observed and photographed while surveying for lycaenids in selected localities of Tamil Nadu. The position of wing held at the time of foraging on flowers or at rest were also observed in the lycaenid butterfly species of the study area.

Host plants of lycaenid butterflies for oviposition: The lycaenid butterflies ovipositing host plants of the selected localities in the survey area were observed and the plant species were photographed. They were identified with the help of botanist from the Department of Botany, Annamalai University.

Pollination beneficiary and nectar yielding plant species of lycaenid butterflies: The lycaenid butterflies pollinating plant species of the study area were recorded in different landscape *viz.,* plains, hill, forest, garden, bushy area *etc*., along with their beneficiary plant species during the study period. All the species of butterflies sighted on different flowering plants species were collected/observed and identified. The nectar yielding plants for lycaenid butterflies of the study area were also recorded along with their beneficiary lycaenid species. All the species sighted on different nectaring plants were collected/observed and identified.

RESULTS AND DISCUSSION

Effect of ant on lycaenid larval behavior and honey dew secretion: The number of attending ants affected the larval behavior on honey dew secretion and tentacle eversions. When the ant, *C. compressus* attended the lycaneid larva by antennal storking on the 7^{th} abdominal segment, the larva raised the tentacles and produce the honey drops and the ant feeds on. When the number of ants having access increased

Districts	Selected localities surveyed
Cuddalore	Annamalainagar (11.38°N and 79.72°E), Kurinjipadi (11.57°N and 76.6°E), Sivapuri (11.38°N and 79.79°E)
Nagapattinam	Sirkali (11.23°N and 79.73°E), Mayiladuthurai (11.10°N and 79.65°E), Kollidam (10.85°N and 79.74°E)
Thanjavur	Orathanadu (10.64°N and 79.22°E), Puthur (10.92°N and 79.27°E), Papanadu (10.28°N and 79.07°E)
Namakkal	Kolli hills (11.24 N and 78.33 E), Senthamangalam (11.30°N and 78.23°E), Rasipuram (11.46°N and 78.18°E)
Salem	Yercadu hills(11.78°N and 78.21°E), Attur(11.59°N and 78.60°E), Omalur(11.74°N and 78.04°E)
Coimbatore	Mettupalayam(11.28°N and 76.94°E), Siruvani (11.16°N and 76.79°E), Thondamuthur (10.98°N and 76.84°E)
Vellore	Yelagiri hills (12.86°N and 79.03°E), Veppamattu (12.86°N and 79.03°E), Pelampattu (12.86°N and 79.03°E)
Tiruvannamalai	Javvadhu hills (12.58°N and 78.83°E), Arani (12.67°N and 79.28°E), Chengam(12.31°N and 78.79°E)
Villupuram	Kalvarayan hills (11.80°N and 78.76°E), Thindivanam(12.23°N and 79.64°E), Kallakkurichi (11.73°N and 78.95°E)
Madurai	Melur(10.05°N and 78.33°E), Tirumangalam(9.91°N and 77.98°E), Usilampatti(9.97°N and 77.8°E)
Tirunelveli	Kutralam(9.89°N and 78.03°E), Vasudevanallur(9.24°N and 77.41°E), Kalakkad(8.51°N and 77.55°E)
Kanyakumari	Thovalai(8.22°N and 77.50°E), Suchindram(8.15°N and 77.46°E), Kulasekharapuram(8.14°N and 77.50°E)

from one to two the larva almost doubled the number of droplets secreted which accounts 2.15 and 3.90 . respectively. The number of ants increased even more, there was no further increase in larval droplet. The tentacle eversions were observed for a period of 20 minutes and maximum eversion was observed as 34.0 times followed by 25.9 times when two and one ants released respectively. Number of tentacle eversions did not differ significantly between treatments (Table 1) (Plate 1a-1e). The *E. cnejus* larva gave significantly more droplets after a simulated attack of ant species. The doubled number of droplets delivered during the five-minute period was noticed as 3.11 immediately following the attack. The rate of tentacle eversions differed even more between the treatments, increasing by about a factor of five minutes after the attack 21.4. The ants responded to the increased effort of the larvae by increasing the degree of attendance (Table 2).

Colourational change of lycaenid butterflies: Four species of lycaenid butterflies were found with colourational changes on the underside of the wings especially in males of Angled Pierrot, Common Cerulean, Common Pierrrot and Gram Blue (Table 3) (Plate 2). In wet season form (WSF) butterflies were seen with dark and more lines or spots on the underside of the wings. The dry season form (DSF) of butterflies was found with markings which were light and less number of spots present on the underside. This might be due to the change in climate and altered condition of foodstuff producing colour markings on the wings. Kehimkar (2008) reported two different forms having dissimilar markings, colour or shapes. The WSF bears a number of eyespots on the underside besides the streaking and dark on the upperside. While in the DSF, the wings are more angular and eyespots are completely absent or reduced to minute dots and unstreaked underside gives a leafy appearance. Such variations are a result of varying environmental factors that help the species in better camouflaging itself for survival in the environmental conditions. The sexes are similar on the underside, although on the upper side males are brighter blue with narrow black borders whereas females had much broader borders. Further, Kunte (2000) also found that dry season form of *Jamides celeno* Cramer, in which the space between the discal bands on both the wings are filled with dark brown whereas the tornal orange crowned black spot is highly reduced in size and orange coloration.

Mud-Puddling and wing position behaviour of Lycaenidae butterflies: The mud-puddling behaviour of lycaenid butterflies were noticed from Angled Pierrot, Common Line Blue, Tiny Grass Blue, Gram Blue and Grass Jewel in the localities like Kolli hills, Mettupalayam dam, Siruvani dam and Pechiparai area respectively (Table 4) (Plate 3). Only males undertake mud puddling in the damp area because they absorb essential elements such as sodium that have been lost during copulation in the form of

Plate 1. Myrmecological studies on *Euchrysops cnejus* in association with ant *Componotus compressus*

Table 2. Lycaenid, *Euchrysops cnejus* larval response to stimulated attacks of ant, *Camponotus compressus*

Interaction between larva and ant	Simulated attack	Control	P
Droplet per 5 minutes	3.11±0.31	2.17±0.39	0.0098
Tentacle eversions per 5 minutes	21.4±0.09	6.9±0.10	0.0009

Table 1. Myrmecological study on the effect of increased ant, *Camponotus compressus* attendance on lycaenid, *Euchrysops cnejus* larval behavior and honey dew secretion

Interaction between larva and ant (Time)	Number of ants released			
	1	2	3	P
Droplets/ 20 minutes	2.15±0.31	3.90±0.40	3.08±0.33	0.017
Tentacle eversions/20 minutes	25.9±5.80	34.0±6.90	22.8±5.00	0.950
Attending ants	0.92±0.60	2.75±0.10	3.83±0.27	<0.001

sperms. The excess water that is absorbed is thrown out of the abdomen in the form of droplets. These lycaenids were preferred to puddle on various nutrient sources like wet soil, manures or decomposing materials.Out of 45 species of lycaenid butterflies were recorded in the study area found

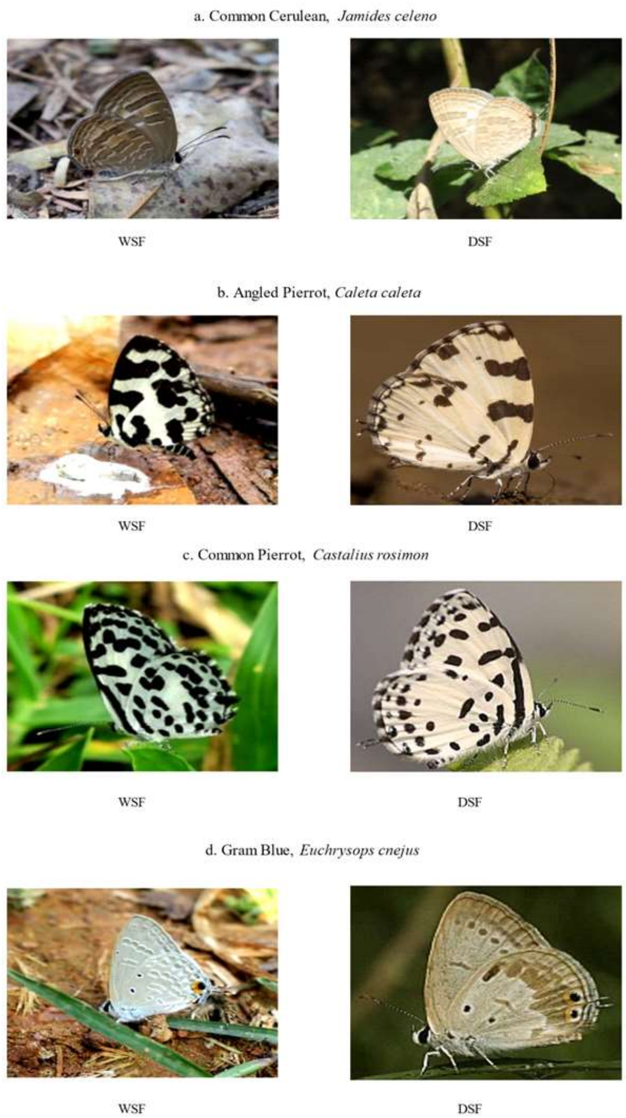

Plate 2. Seasonal diversity (Forms) of lycaenid butterflies in the study area

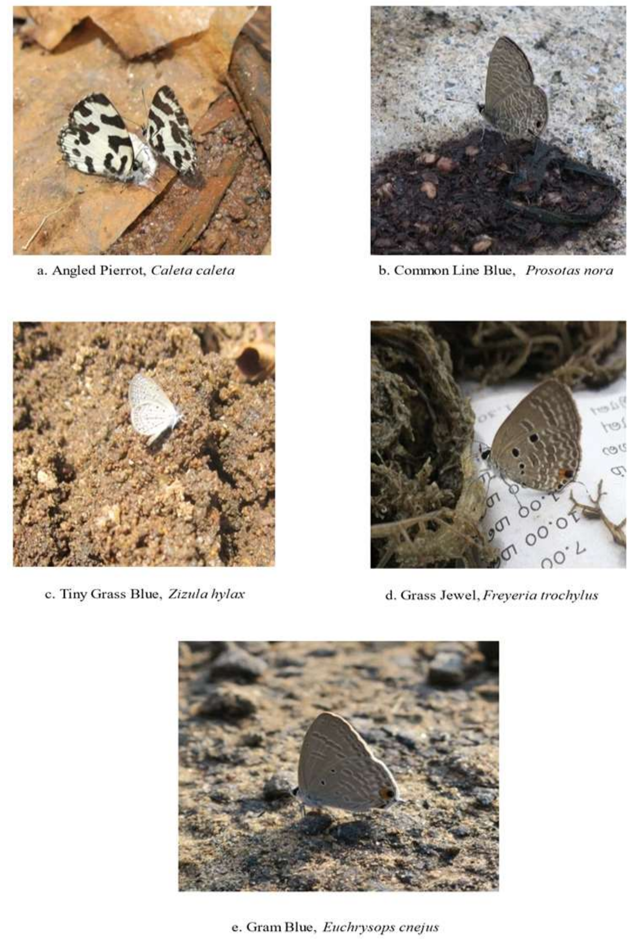

Plate 3. Mud puddling of lycaenid butterflies observed in the study area

Table 4. Mud puddling behaviour of lycaenid butterflies observed in the selected localities study area (2017-2018)

Mud puddling lycaenids	Scientific name	Locality
Angled pierrot	*Caleta caleta*	Kolli hills
Common line blue	*Prosotas nora*	Kolli hills
Tiny grass blue	*Zizulz hylax*	Mettupalayam dam
Gram blue	*Euchryspos cnejus*	Siruvani dam
Grass jewel	*Freyeria trochylus*	Pechiparai dam

Table 3. Colourational change of lycaenid butterflies due to seasonal variation in the study area

Common name	Scientific name	Colouration in male	
		Wet season form	Dry season form
Angled Pierrot	*Caleta caleta*	Wing under side dark parallel lines	Wing under side light parallel lines
Common Cerulean	*Jamides celeno*	Wing under side bright colour with many scattered spot	Wing under side dull colour with few scattered spot
Common Pierrot	*Castalius rosimon*	Wing under side bright colour with uneven spot	Wing under side dull colour with even spot
Gram Blue	*Euchrysops cnejus*	Wing under side bright colour with eye spot	Wing under side dull colour with eye spot and dark hindwing margin

Table 5. Wing position of lycaenid butterfly species observed while foraging at flowers or at rest (2017-2018)

Common name	Scientific name	WF	WS	WUHO	WUA
Apefly	*Spalgis epius*	+	+	-	+
Common Brownie	*Miletus chinensis*	-	-	-	+
Indian Sunbeam	*Curetis thetis*	-	-	+	+
Large Oakblue	*Arhopala amantes*	-	-	+	+
Indian Oakblue	*Arhopala atrax*	-	+	-	+
Common Acacia Blue	*Surendra quercetorum*	-	+	-	+
Leaf Blue	*Amblypodia anita*	-	+	-	+
Yamfly	*Loxura atymnus*	-	-	+	+
Common Onyx	*Horaga onyx*	-	-	+	+
Monkey Puzzle	*Rathinda amor*	-	+	-	-
Guava Blue	*Deudorix isocrates*	-	-	+	+
Common Tit	*Hypolycaena erylus*	-	+	-	+
Cornelian	*Deudorix epijarbas*	-	-	+	+
Common Tinsel	*Catapaecilma elegans*	-	-	+	+
Common Silverline	*Spindasis vulcanus*	-	+	-	+
Common Shot Silverline	*Spindasis ictis*	-	+	-	+
Common Red Flash	*Rapala iarbus*	-	+	-	+
Common Ciliate Blue	*Anthene emolus*	-	+	-	+
Pointed Ciliate Blue	*Anthene lycaenina*	-	+	-	+
Angled Pierrot	*Caleta caleta*	+	-	-	+
Common Pierrot	*Castalius rosimon*	-	+	-	+
Banded Blue Pierrot	*Discolampa ethion*	+	-	-	+
Zebra Blue	*Leptotes plinius*	+	+	-	+
Common Line Blue	*Prosotas nora*	-	+	-	+
Tailless Line Blue	*Prosotas dubiosa*	-	+	-	+
Dark Cerulean	*Jamides bochus*	-	+	-	+
Common Cerulean	*Jamides celeno*	-	+	-	+
Pea Blue	*Lampides boeticus*	-	-	+	+
Rounded Pierrot	*Tarucus nara*	-	+	+	+
Dark Pierrot	*Tarucus ananda*	-	+	+	+
Dark Grass Blue	*Zizeeria karsandra*	-	+	+	-
Pale Grass Blue	*Pseudozizeeria maha*	-	+	+	+
Lesser Grass Blue	*Zizina otis*	-	+	-	+
Tiny Grass Blue	*Zizula hylax*	-	+	-	+
Indian Cupid	*Everes lacturnus*	-	+	+	+
Tailed Cupid	*Everes argiades*	-	+	+	+
Red Pierrot	*Talicada nyseus*	-	+	+	+
Quaker	*Neopithecops zalmora*	-	-	+	+
Gram Blue	*Euchrysops cnejus*	-	+	+	+
Plains Cupid	*Chilades pandava*	-	+	+	+
Lime Blue	*Chilades lajus*	-	+	+	+
Grass Jewel	*Freyeria trochylus*	-	+	+	+
Plain Hedge Blue	*Celastrina lavendularis*	-	-	+	+
Pale Hedge Blue	*Udara dilecta*	+	-	+	+
Transparent 6-Lineblue	*Nacaduba kurava*	-	-	+	+

WF = Wing fluttering; WS = Wing spreading; WUHO = Wings upright and half opened; WUA = Wing upright and adpressed

Table 6. Larval food (plants/insects) of lycaenid butterflies (2017-2018)

Common name	Scientific name	Food plants/insects
Apefly	*Spalgis epius*	*Paracoccus marginatus* (Williams and Granara de Willink), *Planococcus citri* (Risso), *Maconellicoccus hirsutus* (Green)
Indian Sunbeam	*Curetis thetis*	*Pongamina pinnata* (Linn.), *Abrus precatorius* (Linn.), *Derries scandens* (Roxburgh)
Large Oakblue	*Arhopala amantes*	*Terminalia catappa* (Linn.), *Terminalia alata* (Willd), *Terminalia paniculata* (Roth)
Indian Oakblue	*Arhopala atrax*	*Shorea robusta* (Roth)
Common Acacia Blue	*Surendra quercetorum*	*Acacia pinnata* (Willd.), *Acacia caeisa* (Willd.)
Leaf Blue	*Amblypodia anita*	*Olax imbricate* (Roxb.), *Olax scandens* (Roxb.)
Yamfly	*Loxura atymnus*	*Smilax bracteata* (C. Presl), *Dioscorea pentaphylla* (Linn.)
Common Onyx	*Horaga onyx*	*Coriaria nepalensis* (Wall.)
Monkey Puzzle	*Rathinda amor*	*Mangifera indica* (Linn.), *Ixora* spp.
Guava Blue	*Deudorix isocrates*	*Tamarindus indica* (Linn.), *Punica granatum* (Linn.), *Psidium guajava* (Linn.), *Gradenia latifolia* (Ait.)
Common Tit	*Hypolycaena erylus*	*Cinnamomum zeylanicum* (J. Prsel)
Cornelian	*Deudorix epijarbas*	*P. granatum, Aesculus indica (*Wall.), *Lichi chinensis* (Sonn.)
Common Tinsel	*Catapaecilma elegans*	*T. paniculata*
Common Silverline	*Spindasis vulcanus*	*Ziziphus mauritiana* (Lam.), *Ziziphus rugosa* (Lam.)
Common Shot Silverline	*Spindasis ictis*	*Dendrophthoe* sp. (L.F.), *Allophylus cobbe* (Linn.)
Common Red Flash	*Rapala iarbus*	*Z. rugosa*
Common Ciliate Blue	*Anthene emolus*	*T. paniculata, Saraca asoca* (Roxb.)
Angled Pierrot	*Caleta caleta*	*Z. rugosa, Z. mauritiana*
Common Pierrot	*Castalius rosimon*	*Z. jujube* (Mill.), *Z. mauritiana. Z. rugosa*
Banded Blue Pierrot	*Discolampa ethion*	*Z. jujube, Z. maritiana.*
Zebra Blue	*Leptotes plinius*	*Mimosa* spp (Linn.)*, Sesbania bispinosa* (Jacq.)
Common Line Blue	*Prosotas nora*	*Acacia torta (Roxb.), Mimosa* spp.
Tailless Line Blue	*Prosotas dubiosa*	*Acacia* spp., *M. pudica (*Linn.), *Leucena* spp. (Benth.)
Dark Cerulean	*Jamides bochus*	*Xylia dolabrifornis* (Roxb.), *P. pinnata, Crotolaria* spp.
Common Cerulean	*Jamides celeno*	*P. pinnata, S. asoca*
Pea Blue	*Lampides boeticus*	*Vigna radiata* (Linn.), *Vigna mungo* (Linn.), *Cajanus cajan* (Linn.), *Vigna sinensis* (Linn.), *Crotalaria* spp., (Linn.)
Rounded Pierrot	*Tarucus nara*	*Zizphus* spp.
Dark Pierrot	*Tarucus ananda*	*Jasminum* spp. (Linn.) *Zizyphus* spp.
Dark Grass Blue	*Zizeeria karsandra*	*Tribulus terrestris* (Linn.),*Amaranthus spinosus* (Linn.),
Pale Grass Blue	*Pseudozizeeria maha*	*Oxalis corniculata* (Linn.)
Lesser Grass Blue	*Zizina otis*	*M. pudica*
Tiny Grass Blue	*Zizula hylax*	*Hygrophila auriculata (Schumach.)*,*O. corniculata*
Indian Cupid	*Everes lacturnus*	*Desmodium* spp. (Desv.)
Tailed Cupid	*Everes argiades*	*Medicago lupulina (*Linn.), *Trifolium* spp. (Linn.)
Red Pierrot	*Talicada nyseus*	*Kalanchoe pinnata* (Adans.)
Quaker	*Neopithecops zalmora*	*Glycosmis arborea* (Retz.)
Gram Blue	*Euchrysops cnejus*	*Vigna cylindrica (*Linn.), *V. trilobata, V. mungo, C. cajan*
Plains Cupid	*Chilades pandava*	*Bauhinia vahlii* (Linn.), *Holoptelea intergrifolia* (Planch.)
Lime Blue	*Chilades lajus*	*Citrus maxima* (Linn.), *Atalantia racemosa* (Wight and Arn.), *Citrus grandis* (Linn.)
Plains Cupid	*Chilades pandava*	*Acacia* spp. *Cycas revolute* (Thunb.)
Grass Jewel	*Freyeria trochylus*	*P. sativum, O. corniculata*
Transparent 6-Lineblue	*Nacaduba kurava*	*Waltheria indica* (Linn.)

with WF, WS, WUHO and WUA position during rest and foraging on flowers (Table 5). Wing position of different butterflies while foraging on flowers were recorded by Venkata Ramana (2010) in Eastern Ghats area of Andhra Pradesh and observed that majority of lycaenids were noticed with wing upright adpressed (WUA) position.

Larval food (plants/insects) of Lycaenidae butterflies: A total of 42 plant species were observed as lycaenid ovipositing plants or host plants. The lycaenids were more attracted to various species of plants (Table 6). Most of the plant species were belongs to Fabaceae, Rhamnaceae and Combretaceae family. This might to be due to the larval host plants belong to the above family is available for lycaenids survival and development in the study area. Tiple et al (2009) reported that herbs namely, *Tridax procumbens* and *Tephrosia purpurea* were more used by lycaenid butterflies.Venkata Ramana (2010) reported that the lycaenids like *Talicada nysus* lays eggs on *Bryophyllum*

Table 7. Important plant species pollinated by lycaenid butterflies (2017-2018)

Common name	Scientific name	Beneficiary Plant/species	Family
Apefly	*Spalgis epius*	*L. camara* (Linn.)	Verbenaceae
Indian Sunbeam	*Curetis thetis*	*P. pinnata* (Linn.)	Fabaceae
Large Oakblue	*Arhopala amantes*	*Terminalia catappa* (Linn.) *T. alata* (Heyne ex Roth)	Combretaceae
Indian Oakblue	*Arhopala atrax*	*Shorea robusta* (Roth)	Dipterocarpaceae
Common Acacia Blue	*Surendra quercetorum*	*Acacia pinnata* (Linn.)	Fabaceae
Leaf Blue	*Amblypodia anita*	*Olax imbricate* (Roxb.)	Olacaceae
Yamfly	*Loxura atymnus*	*Smilax bracteata* (C.Persl)	Smilacaceae
Common Onyx	*Horaga onyx*	*Coriaria nepalensis* (Wall.)	Coriariaceae
Common Tinsel	*Catapaecilma elegans*	*Terminalia paniculata* (Roth)	Combretaceae
Common Pierrot	*Castalius rosimon*	*Ziziphus* spp. *(Mill.)*	Rhamnaceae
Red Pierrot	*Talicada nyseus*	*T. procumbens* (Linn.)	Asteraceae
Lime Blue	*Chilades laius*	*Citrus* spp. (Linn.)	Rutaceae
Pea Blue	*Lampides boeticus*	*T. procumbens*	Asteraceae
Pale grass blue	*Pseudozizeeria maha*	*Psidium guajava* (Linn.)	Myrtaceae
Common Line Blue	*Prosotas nora*	*Acacia torta* (Roxb.), *M. pudica*(Linn.)	Fabaceae
Tailless Line Blue	*Prosotas dubiosa*	*M. pudica*	Fabaceae
Common Red Flash	*Rapala iarbus*	*Nephelium lappaceum* (Linn.)	Sapindaceae
Common Ciliate Blue	*Anthene emolus*	*T. paniculata*	Combretaceae
Indian Cupid	*Everes lacturnus*	*P. guajava*	Myrtaceae
Zebra Blue	*Leptotes plinius*	*L. camara*	Verbenaceae
Guava Blue	*Deudorix isocrates*	*P. guajava*	Myrtaceae
Tiny Grass Blue	*Zizula hylax*	*L. camara*	Verbenaceae
Gram Blue	*Euchrysops cnejus*	*L. camara*	Verbenaceae
Dark Cerulean	*Jamides bochus*	*P. pinnata*	Fabaceae
Common Cerulean	*Jamides celeno*	*Ziziphus* spp. (Lam.)	Rhamnaceae
Indian Sunbeam	*Curetis thetis*	*P. pinnata*	Fabaceae
Dark Pierrot	*Tarucus ananda*	*Ziziphus* spp	Rhamnaceae
Rounded Pierrot	*Tarucus nara*	*T. procumbens*	Asteraceae
Plains Cupid	*Chilades pandava*	*Bauhinia vahlii* (Linn.)	Fabaceae
Lime Blue	*Chilades lajus*	*C. maxima*	Rutaceae
Plains Cupid	*Chilades pandava*	*Cycas revolute* (Thunb.)	Cycadaceae
Grass Jewel	*Freyeria trochylus*	*Oxalis corniculata* (Linn.)	Oxalidaceae
Transparent 6-Lineblue	*Nacaduba kurava*	*Embelia robusta* (Burm.)	Primulaceae
Quaker	*Neopithecops zalmora*	*Glycosmis arborea* (Retz.)	Rutaceae

calycinum, *Castalius rosimon* lays egg on *Ziziphus jujube* and *Rathinda omor* lays exclusively on *Ixora* spp and this coincides with *Curetis thetis* lays on *Pongamia glabara* only. Nimbalkar et al (2011) reported that the herbs namely, *Celosia argentea*, *T. procumbens* and *T. purpurea* were more used by butterflies probably due to the act that the flowering

Table 8. Important nectar food plants of lycaenid butterfly species (2017-2018)

Common name	Scientific name	Nectar yielding plant species
Apefly	*Spalgis epius*	*L. camara*
Common Acacia Blue	*Surendra quercetorum*	*Trifolium repens, T. procumbens*
Indian Sunbeam	*Curetis thetis*	*P. pinnata* (Linn.), *L. camara*
Large Oakblue	*Arhopala amantes*	*Kalanchoe laciniata* (Adans.)
Indian Oakblue	*Arhopala atrax*	*Ziziphus* spp., (Lam.), *Achyranthes aspera* (Linn.)
Grass Jewel	*Freyeria trochylus*	*Flacourtia indica* (Burm. f.)
Bright Babul Blue	*Azanus ubaldus*	*Crotalaria capensis* (Linn.)
Transparent 6-Lineblue	*Nacaduba kurava*	*Ixora* spp, *T. purpurea*
Quaker	*Neopithecops zalmora*	*Ziziphus* spp. *Celosia argentea* (Linn.)
Tailless Line Blue	*Prosotas dubiosa*	*Ziziphus* spp. *T. procumbens*
Common Red Flash	*Rapala iarbus*	*Saraca asoca* (Roxb.), *Z. mauritiana.*
Leaf Blue	*Amblypodia anita*	*Meyna pubescens* (Roxb.)
Yamfly	*Loxura atymnus*	*Rumex* spp. (Linn.), *T. procumbens*
Common Onyx	*Horaga onyx*	*Shorea robusta* (Roth),*Ziziphus* spp
Common Tinsel	*Catapaecilma elegans*	*Z. jujube* (Mill.), *Z. mauritiana*
Common Pierrot	*Castalius rosimon*	*Parthenium hysterophorus* (Linn.)
Angled Pierrot	*Caleta caleta*	*Ziziphus* spp.
Common Pierrot	*Castalius rosimon*	*Cynotis villosa* (Spreng.)
Banded Blue Pierrot	*Discolampa ethion*	*L. camara, T. procumbens*
Zebra Blue	*Leptotes plinius*	*C. argentea, T. procumbens*
Common Line Blue	*Prosotas nora*	*Acacia torta* (Roxb.), *Bidens pilosa (Linn.)*
Dark Cerulean	*Jamides bochus*	*L. camara,T. purpurea*
Common Cerulean	*Jamides celeno*	*C. argentea, L. camara*
Pea Blue	*Lampides boeticus*	*C. argentea, P. pinnata*
Rounded Pierrot	*Tarucus nara*	*Ziziphus* spp., *Aegle marmelos* (Linn.)
Dark Pierrot	*Tarucus ananda*	*Ziziphus* spp., *Murraya koenigii* (Linn.)
Dark Grass Blue	*Zizeeria karsandra*	*L. camara*
Pale Grass Blue	*Pseudozizeeria maha*	*T. purpurea, C. argentea,*
Tiny Grass Blue	*Zizula hylax*	*L. camara*
Indian Cupid	*Everes lacturnus*	*B. pilosa,Capparis rheedii* (Linn.)
Red Pierrot	*Talicada nyseus*	*T. procumbens, Capparis zeylanica* (Linn.)
Gram Blue	*Euchrysops cnejus*	*L. camara, Ixora* spp
Plains Cupid	*Chilades pandava*	*Galinsoga parviflora* (Cav.)
Lime Blue	*Chilades lajus*	*Urena lobata* (Linn.), *Crotalaria capensis* (Linn.)
Plain Hedge Blue	*Celastrina lavendularis*	*Emilia sonchifolia* (Linn.)
Grass Jewel	*Freyeria trochylus*	*Rumex* spp., *T. procumbens*
Pale Hedge Blue	*Udara dilecta*	*S. robusta,Ziziphus spp*
Transparent 6-Lineblue	*Nacaduba kurava*	*Z. jujube, Z. mauritiana*
Quaker	*Neopithecops zalmora*	*P. hysterophorus*
Common Tinsel	*Catapaecilma elegans*	*Z. mauritiana, T. procumbens*

period of these herbs is throughout the year. The shrubs namely, *Calotropis gigantean* and *Lanatana camara* also had a flowering period throughout the year. Hence, they are most used by butterflies as their food plants. Kanagaraj and Kathirvelu (2018) reported 20 plant species belong to Fabaceae, Rhamnaceae, Amaranthaceae, Zygophyllaceae, Acanthaceae, Oxalidaceae, Smilacaeae, Olacaceae and Combretaceae families in Annamalainagar. Among them, Fabaceae family was predominant with major larval host plants of lycaenids of Annamalainagar. The lycaenid populations were recorded at the time when the host plants in suitable phenophase for growth of the caterpillars. Kunte (2000) reported that important larval food plants of Lycaenidae were *Butea monosperma,Crotalaria* spp., *Millettia peguensis, Vigna cylindria, P. pinna* and *Xylia xylocarapa.* Pale et al (2015), they reported that the Pea Blue butterfly is known to feed on many Fabaceae plants including several *Crotalaria* spp, and the present study clearly indicated that the *Vigna trilobata* was the most desirable plant for oviposition of this lycaenid butterflies. Further, Kathirvelu and Gopianand (2023) reported the *Lampides boeticus* was very common in agro-ecosystem.

Plant species pollinated by lycaenid butterflies and nectar yielding plants: Among the 34 plant species benefited from butterflies, the plants belong to the families namely, Verbenaceae was pollinated by many species of lycaenid butterflies (Table 7). Most lycaenids were attracted to flowers with yellow/ white/ reddish in colour. Thakur and Mattu (2010) also reported that the flowers of family Asteraceae were most attracted to various butterfly species. The flowers of the family Mimosaceae, Dioscoreaceae, Lauraceae, Rubiaceae, Melastomataceae, Myrtaceae, Rhamnaceae, Zingiberaceae, Fabaceae, Oxalidaceae, Rutaceae were attracted many lycaenid butterflies as reported by Bora and Meitei (2014). The nectar yielding plants species (40) of the study area were identified as *Zizyphus* spp., *Lantana camara, Celosia argenta, Tridex procumbens, Tephrosia purpurea*. Most of the lycaenid butterfly species were depend on *Zizyphus* spp., *T. procumbens, C. argentea, Saraca asoca, Parthenium hysterophorus* and *Bidens pilosa* for their nectar food in the study area (Table 8). The butterfly species observed in the study area were strongly associated with the plants of the family Fabaceae, both as the caterpillars and adults. Sultana *et al.* (2017) observed that the lycaenids are small sized butterflies with small proboscis. They chose flowers having similar and nearly similar corolla tube length compare to their proboscis length.

CONCLUSION

The lycaenids showed their strong mutualistic behaviour with ants for their survival in the environment by benefitting each other. The larval response in delivering the honey dew droplets is proportional to the degree of ants attended. Colourational change revealed that there were two forms *viz*., WSF and DSF differentiated with markings and spots. Places near to water bodies or damp area was preferred by the lycaenids for mud puddling and the wing position of the butterflies were found with wing upright and adpressed position while at rest than other positions. Totally 64 plant species were observed as host plants of lycaenids in which Fabaceae, Rhamnaceae and Combretaceae were most preferred. The plant species belong to Verbanaceace was most benefitted by pollination service of lycaenids and they were well attracted to yellow, white and red colour.Most of the lycaenid butterfly species were depend on *Zizyphus* spp., *T. procumbens, C. argentea, Saraca asoca, Parthenium hysterophorus* and *Bidens pilosa* for their nectar food in the study area. The lycaenids were diversified in the study area and had a multiple dimension as predator, pest, pollinator and also their protective behaviours by having mutualistic association with ants. Further, they are successful in reproduction with their behaviours like puddling and change their forms according to the seasons for survival.

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Identification and Evaluation of Soil-Derived Microbial Strains for Thiamethoxam Biodegradation

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***Abstract*:** This study investigates the enrichment, isolation, and characterization of thiamethoxam-degrading bacterial species from cotton field soils. Soil previously exposed to xenobiotics was used to enrich microbial biomass in MSMT broth, leading to the isolation of nine distinct bacterial species based on colony morphology. These isolates were screened for their ability to degrade thiamethoxam in liquid cultures, revealing that bacterial isolate TY achieved the highest degradation rate of 35.52% over 15 days. Taxonomic identification through 16S rDNA sequencing identified isolate TY as a novel strain of *Salmonella enterica* subsp. *enterica* with a reduced sequence identity of 96% compared to reference strains. The bacterial isolate TY was non-pathogenic, as determined by Congo red agar assays. Optimal growth conditions for TY were identified at 37°C and pH 6.5, and its thiamethoxam degradation was influenced by the availability of carbon and nitrogen sources. This research highlights the potential of *S. enterica* strain TY for bioremediation of thiamethoxam and contributes to the understanding of pesticide degradation by non-traditional bacterial species.

***Keywords*:** Thiamethoxam, Biodegradation, *Salmonella enterica* subsp. *Enterica*, Pesticide metabolism, 16S rDNA sequencing

Over recent decades, various chemical compounds, including organochlorines, triazines, carbofuran, phenoxyacetates, and organophosphates have been extensively used in agriculture over the decades to protect crops from pests and enhance yield to meet the demands of a growing population (Fulton et al 2014). While these pesticides are effective in pest control, only a small fraction (about 1%) of the applied pesticide reaches the target organisms and the remainder contaminates the environment, adversely affecting public health and beneficial biota by contaminating soil, water, and the atmosphere (Elhamalawy et al 2024). In response to these environmental concerns, new classes of chemical compounds, such as neonicotinoids, were developed in the 1970s. These include imidacloprid and thiamethoxam, which were introduced in the 1990s (Fulton et al 2014, Silcox and Vittum 2008). Thiamethoxam is a second-generation neonicotinoid insecticide effective against a broad range of insects. It acts on the nicotinic acetylcholine receptors (nAChRs) of insects, leading to neuromuscular paralysis and death (Mohamed 2009). Despite its effectiveness, thiamethoxam has the potential to leach into groundwater due to its weak soil binding, thus contaminating the ecosystem and potentially causing issues such as "colony collapse disorder" in bees and liver, kidney, and brain damage in laboratory albino male rats (Henry et al 2012, Khaldoun-Oularbi et al 2017). This highlights the need for efficient, eco-friendly methods to degrade such compounds.

To mitigate these environmental risks, bioremediation via microbial degradation presents a viable solution, as certain microorganisms can metabolize these pesticides into less harmful substances. For instance, *E. adhaerens* TMX-23, *Pseudomonas* sp., *Acinetobacter* sp., *Enterobacter* sp., and *Bacillus* sp. have been identified as capable of degrading thiamethoxam through specific metabolic pathways (Zhou et al 2013, Hegde et al 2017). Since microbial degradation using selected bacterial species offers the most attractive, and cost-effective bioremediation approach. This study focuses on isolating bacterial species from agricultural soils with high thiamethoxam-degrading potential, and evaluating their effectiveness in thiamethoxam-fortified liquid media, paving the way for future bioremediation applications.It could contribute to the advancement of sustainable agricultural practices by enhancing our understanding of microbial capabilities for pesticide degradation and fostering the development of effective bioremediation strategies to address pesticide pollution.

MATERIAL AND METHODS

Bacteriological media: Two types of media were used: Luria-Bertani (LB) for general purposes and Mineral Salt Medium (MSM) for enriching thiamethoxam-degrading bacterial species. To solidify LB and MSM, 1.6% bacteriological agar (S. d. fine-chem Ltd, Mumbai) was added before autoclaving. MSM was supplemented with thiamethoxam stock (10 mg/ml in acetone) to achieve concentrations of 20 or 50 µg/ml as the sole source of carbon, nitrogen, and energy.

Enrichment, isolation, and purification of bacterial species from soil: Soil samples (~100 g each) were collected from a cotton field with a history of thiamethoxam application at Punjab Agricultural University, Ludhiana (30.904751, 75.806932 https://maps.app.goo.gl/9Qug NGA6bMxPPR5j6). These samples were mixed, stored at 4°C, and processed in the lab. A 50 g aliquot of the mixed soil was suspended in 250 ml of 0.05 M potassium phosphate buffer (pH 7.0), filtered, and centrifuged to obtain bacterial biomass. The pellet was re-suspended in buffer, and inoculated into MSMT containing thiamethoxam (20 µg/ml). The culture was grown at 28±2°C with shaking. Enrichment was followed by plating on solid MSMT-agar to isolate colonies. Colony characteristics were examined under a stereomicroscope, and Gram staining was performed on LB broth cultures.

Screening of bacterial species for thiamethoxam degradation in liquid cultures: Thiamethoxam degradation potential was assessed in 15 ml MSM broth (50 µg/ml thiamethoxam) inoculated with 500 µl ofovernight grown bacterial culture (10^8 CFUml^{-1}). The cultures were incubated at 37±1°C with shaking (120 rpm) for 15 days. Samples (1 ml) were taken at 3, 8, and 15 days to measure thiamethoxam levels. Control flasks without bacterial inoculation were included for comparison. Culture broth samples were extracted using dichloromethane, concentrated, and reconstituted in acetone. Thiamethoxam content was quantified using GLC.The degradation rate, half-life and correlation coefficient (R^2) was calculated to assess the kinetics of degradation. The relative thiamethoxam degradation potential of the different bacterial species was interpreted in terms of the half-life ($t_{1/2}$) period of thiamethoxam in the presence of growth of specific bacterial species(Mandal et al 2014, Rana et al 2015).

Taxonomic identification of bacterial species via 16S ribosomal DNA (rDNA) Sequencing

Amplification of 16S ribosomal DNA from total bacterial DNA: Total DNA was isolated from bacterial cell pellets (~20 mg) obtained from a 48 hrs grown culture in LB, using a CTAB method. Using this DNA as template, 16S rDNA was amplified with QUGP Fn5: 5'-actcctacgggaggcagcag-3' and QUGP-Rn2: 5'-tgacgggcggtgtgtacaag-3' gold primers (Jariyal et al 2014). The size of amplified bands was ascertained by co-running a molecular weight standard (100 bp DNA ladder plus, Fermentas Life Sciences) along with the samples in the gel.

Purification of PCR product, cloning and sequence determination: The agarose block containing the specifically amplified 16S rDNA band (1073bp) was excised from the agarose gel and transferred to a 1.5 ml Eppendorf tube. DNA fragments from this gel band were purified using 'QIAquick Gel Extraction Kit' (Qiagen) as per manufacturer's protocol. The purified DNA fragments were ligated into a pTZ57R/T- a sequencing plasmid vector and the product was transformed into *Escherichia coli* DH5-alpha host cells using 'InsTAcloneTM PCR Product Cloning Kit' (Fermentas Life Sciences) as per manufacturer's protocol. The authenticity of the cloned insert as the target 16S rDNA fragment in this recombinant plasmid was ascertained by positive amplification of a PCR fragment of the desired size (1073 bp) with QUGP gold primers using this recombinant plasmid DNA as a template as described earlier. The information on the nucleotide sequence of the cloned 16S rDNA fragment was obtained for both strands through custom sequencing services of 'M/S Xcelris Labs, Ahmedabad, India' and the final sequence was edited using DNA software Chromaslite 2.01 (Technelysium Pty Ltd, Australia), and CLC Sequence Viewer 6.5.4 (CLC bio A/S).

Analysis of sequence data for taxonomic identification of the bacterial isolate: The 16S rDNA sequence corresponding to a bacterial isolate was blasted in the 'Nucleotide blast program' of the 'National Center for Biotechnology Information' (available at www.ncbi.nlm.nih .gov/Blast). Phylogenetic analysis of the 16S rDNA sequences of isolated bacterial species and bacterial species showing closer sequence homologies was derived using 'create tree' function of CLC Sequence Viewer 6.5.4 (CLC bio A/S) through 'nearest neighbor algorithm with 100 bootstrap replications'. Polymorphic nucleotides between the isolated bacterial species and species showing the closest nucleotide homology were identified using the 'create alignment' function of the above program.

Congo redagar assay for pathogenicity evaluation: Pathogenicity of isolated strains was screened using Congo red agar (CRA) assay *as per* Agenta et al (1997) which is a fast method. Briefly, a loopful of a bacterial culture (bacterial isolate TY) grown overnight in LB medium was streaked onto a Congo red agar plates (1% Bacto tryptone, 0.5% yeast extract, 40 µgml^{-1} Congo red dye, 1.5% agar) incubated at 28°C. The test was performed in triplicate. The plates were observed after 24 hrs for the appearance of red and white colonies as an indicator of potentially pathogenic, and non-pathogenic colonies, respectively (Malcova et al 2008). The red color colony formed on media containing the dye was due to the adsorption of Congo red on the surface of the bacterial cell, to the ions which predominate at the surface, and to the production of acid or alkali by the bacterium during growth (Yakupova et al 2019).

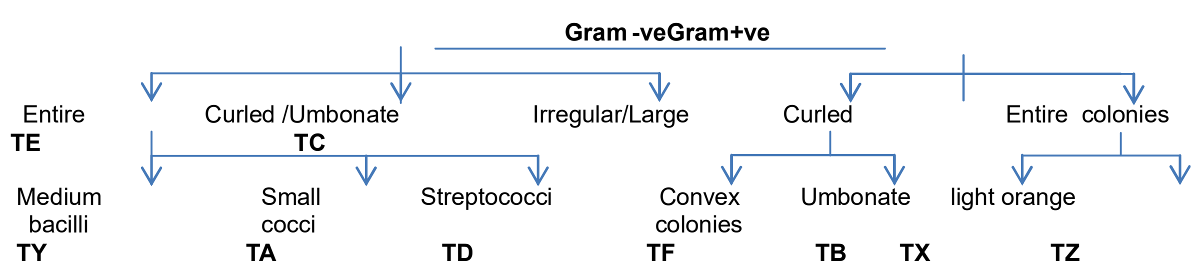
Effect of cultural parameters on bacterial growth: The ability of bacterial species to potentially metabolize different insecticides is directly related to their growth rate (Chishti and Arshad 2012). Therefore, the effect of different cultural parameters- initial medium pH (5.5, 6.0, 6.5, 7.0, 7.5, 8.0, 8.5 & 9.0), incubation temperature (32°, 37° and 42°C) and aeration (shaking vs. stationary conditions) on the growth of bacterial isolate (in terms of OD_{600}) was studied in 15 ml of MSM broth supplemented with glucose at 0.5% level (MSMG) as a sole source of carbon and energy. Each medium aliquot was inoculated with 300 µl of an overnight grown culture of a bacterial isolate to provide an initial OD_{600} of 0.030±0.005. Using one ml aliquots of culture broth drawn at regular intervals of 24 hrs, the growth of the bacterial isolate was recorded in terms of OD_{600} in an 'Eppendorf Biophotometer' up to 7 days.

Effect of supplemented carbon and nitrogen sources on thiamethoxam degradation: The effect of glucose and ammonium sulfate as added carbon, and nitrogen sources on thiamethoxam degradation by selected bacterial species was studied in thiamethoxam supplemented (@ 50 $\mu g ml^{-1}$) MSM broth and raised with optimum pH. Glucose was used at a constant level of 0.1% to provide 0.04% carbon. However, ammonium sulfate as a nitrogen source was studied at two different levels (0.1 and 0.2%) to provide a C:N ratio of 1:1.34 and 1:1.67. So, abbreviations C_0N_0, C_0N_1, C_1N_1, and C_1N_2 represented C_0- No glucose; C_1- 0.1% glucose, N_0- No Nitrogen, N_1, and N_2- 0.1%, and 0.2% ammonium sulfate, respectively. Fifteen ml of so prepared media were inoculated with the bacterial inoculums to provide initial OD_{600} of 0.030±0.005 and growth allowed at optimum temperature in an orbital shaking incubator (120 rpm). One set of conical flasks containing thiamethoxam but without inoculum served as control. After 15 days of growth, the whole medium was analyzed for bacterial growth (OD_{600}) and contents of thiamethoxam through GLC as described earlier.

RESULTS AND DISCUSSION

Enrichment and isolation of thiamethoxam-metabolizing bacterial species: Soil samples previously exposed to xenobiotics, such as those from cotton fields treated with thiamethoxam, typically harbor higher microbial diversity and degradation capabilities compared to untreated soils. Enrichment of microbial biomass from these soils in MSMT broth led to observable increases in turbidity, indicative of active microbial growth. Pour plating of the enriched broth on MSMT-agar yielded several distinct bacterial colonies, which were morphologically categorized into nine types. These bacterial isolates formed circular or irregular colonies, but differed in their colony color (creamy, gray, light orange), colony size (small, medium, large) and colony margin (entire, curled, rhizoid). Three species (TC, TE & TY) produced single rod-shaped cells; while in the case of six other species, cells were either single-celled cocci (TA, TB, TF, TX, TZ) or short-chain streptococci (TD). These isolates varied in colony shape, color, size, and Gram staining characteristics, with four of these species (TB, TF, TX, TZ) were gram-positive, and others were gram-negative in reaction (Fig. 1).

Screening of isolated bacterial species for thiamethoxam degradation: The thiamethoxam degradation potential of the isolated bacterial species was assessed in liquid cultures over a 15-day period. The control cultures, which were uninoculated, exhibited a minimal degradation rate of 8.80%. Among the bacterial isolates, TF showed no thiamethoxam degradation, while the remaining eight isolates demonstrated varying degrees of degradation. The highest degradation was achieved by isolate TY, which reduced thiamethoxam by 35.52%, followed by TD, TX, TB, TZ (Table 1). Notably, degradation increased progressively with incubation time (up to 15 days). Isolate TY exhibited the most efficient degradation, with a half-life of 28.13 days, significantly lower than the control's half-life of 103.79 days, showed that degradation of thiamethoxam in control without microorganism is slow or negligible (Table 2). Regression analysis estimates the relationships among variables whereas half-life ($t_{1/2}$) or DT_{50} find out the time taken for the disappearance of given material from its initial concentration



* Colony characteristics were recorded visually under 10X magnification of a stereomicroscope. Colony size was rated as small: 1-2 mm, medium: 2-3 mm and large: more than 3 mm in diameter

** Cell characteristics were recorded on 48 hr grown broth cultures in LB at 100X magnification under a phase contrast microscope

Fig. 1. Differentiation amongst isolated bacterial species based upon gram's reaction and morphological characteristics

to half of its value (Rana and Gupta 2019). The correlation coefficient of control (0.96) along with other sample was less than 0.99, so thiamethoxam degradation in all samples did not follow first-order reaction (Rana and Gupta 2019). Similarly, Zhou et al (2013) reported *E. adhaerens* TMX-23, Jariyalet al (2014) *Pseudomonas* sp., Myresiotis et al (2011) reported *Bacillus amyloliquefaciens* IN937a, *B. pumilus* SE34, and *B. subtilis* FZB24, Wang et al (2011) reported *Acinetobacter* sp. TW, and *Sphingomonas* sp. TY in liquid medium that have ability to degrade insecticide as discussed in the above section.

Taxonomic identification of bacterial species ty based on 16S rDNA sequencing: The 16S rDNA gene sequence is a universally accepted genetic marker for the taxonomic identification of bacterial species (Schmalenberger et al 2001). Thus, a series of 'Al-Quds University General & Golden Primers' (QUGP) has become available, which enables the amplification of the 16S rDNA from most of the known and unknown bacterial species. However, no single QUGP primer set could amplify the target 16S rDNA region from bacterial specie TY. Therefore, the primer sets for amplification of this region from TY isolate were identified through multiple amplifications using all the different QUGP primer sets. As a result, the 16S rDNA region of the TY bacterial specie was amplified using QUGP golden primer set, QUGPFn5- QUGP-Rn2 to result in amplification of 16S rDNA fragments of ~1073 bp (Fig. 2). The edited nucleotide sequence of the amplified 16S rDNA from bacterial specie TY was submitted to the GenBank database and is available as GenBank Acc # KF 527575. Blasting of the 16S rDNA sequence of bacterial isolate TY with the GenBank database using the 'Nucleotide Blastn tool' of 'NCBI" resulted in >100 homology hits out of which 10 hits with 100% query coverage, maximum score and lowest e-value (0.00) (Table 3). The data showed that bacterial specie TY holds maximum 16S rDNA sequence homology score (1768) with three different strains of *Salmonella enterica* subsp. enterica serovar Heidelberg (GenBank Acc #, CP003416.1, CP001120.1, and CP004086.1) but with the reduced identity of 96%. Figure 3 illustrates the phylogenetic tree constructed from the 16S rDNA sequences of *Salmonella enterica* subsp. *enterica* strain TY alongside ten other bacterial species. This phylogenetic distribution distinctly placed the bacterial isolate TY nearest to two strains (B182- CP003416.1 & SL476- CP001120.1) of *S. enterica* subsp. enterica serovar Heidelberg. Thus, based upon phylogenetic distribution and

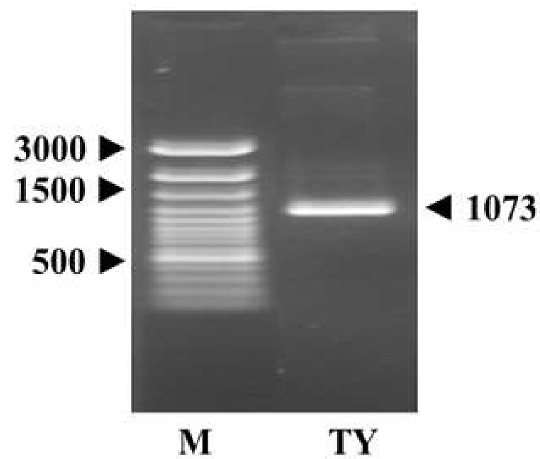


Fig. 2. PCR amplification of 16S rDNA fragments (1073 bp) from total DNA of bacterial specie TY using QUGP golden primer set (QUGP-Fn5 - QUGP-Rn2). M is 100bp DNA ladder (Fermentas Life Sciences). Sizes of DNA bands are given in base pairs (bp)

Table 1. Thiamethoxam degradation by isolated bacterial species after different periods of growth in the MSMT liquid culture

Bacterial species	3 day		8 day		15 day	
	1	2	1	2	1	2
TA	45.36±0.65	7.76	43.22±0.76	12.11	41.00±0.72	16.63
TB	41.16±0.54	16.31	40.65±0.65	17.34	36.45±0.59	25.88
TC	43.46±0.76	11.63	40.93±0.86	16.77	39.12±0.89	20.45
TD	45.06±0.86	8.37	43.32±0.78	11.91	34.47±0.69	29.91
TE	46.09±0.73	6.28	43.77±0.82	11.00	39.02±0.71	20.65
TF	47.73±0.83	2.95	45.54±0.71	7.40	45.06±0.76	8.37
TX	45.06±0.63	8.37	36.63±0.58	25.52	35.79±0.65	27.22
TY	36.45±0.68	25.88	34.49±0.71	29.87	31.71±0.61	35.52
TZ	44.39±0.85	9.74	42.63±0.90	13.32	38.19±0.82	22.35
Control	48.74±0.78	0.89	46.95±0.83	4.53	44.85±0.64	8.80

Data is mean±SE of triplicate values each. Mean thiamethoxam concentration under all treatments at 0 day was estimated to be 49.18±0.0.64 μg ml^{-1}
1- Total thiamethoxam residue (μg ml^{-1}), 2 Percent thiamethoxam reduction

maximum score but with reduced homology, the bacterial species TY was identified as a new strain of *S. enterica* subsp. enterica serovar Heidelberg and was named as *S. enterica* subsp. enterica strain TY. The alignment of 16S rDNA regions of bacterial species TY, and the reference strain (*S. enterica* subsp. enterica serovar Heidelberg strain B182) resulted in the identification of 38 polymorphic nucleotides that differentiated between the newly isolated *S. enterica* subsp. enterica strain TY from the reference strain (Fig. 4). Besides, though bacterial species TY has been assigned strains of *S. enterica* subsp. enterica serovar Heidelberg, but the reduced identity of 96% between these two species/strains, the former demands taxonomic revision, pending availability of 16S rDNA data on more new types of

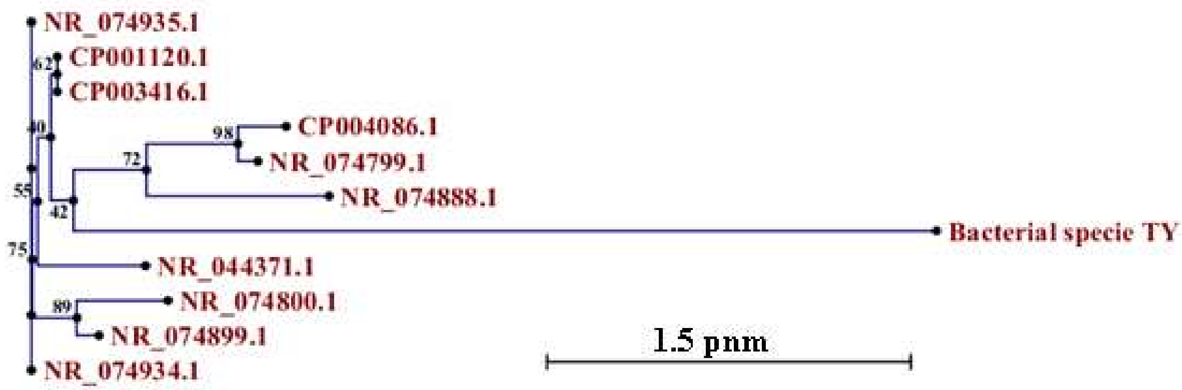


Fig. 3. Bootstrap dendrogram of 16S rDNA nucleotide sequences of ten different subspecies of *S. enterica* showing closest homology with bacterial specie TY, generated using distance based neighbor joining algorithm and 100 bootstrap resembling steps. Bacterial species are indicated by their respective GenBank Accession numbers as given in Table 3. Bar represents sequence deviation in term of percent nucleotide mutations (indicator of % substitutions). The frequency of each group in dendrograms is presented behind the respective node

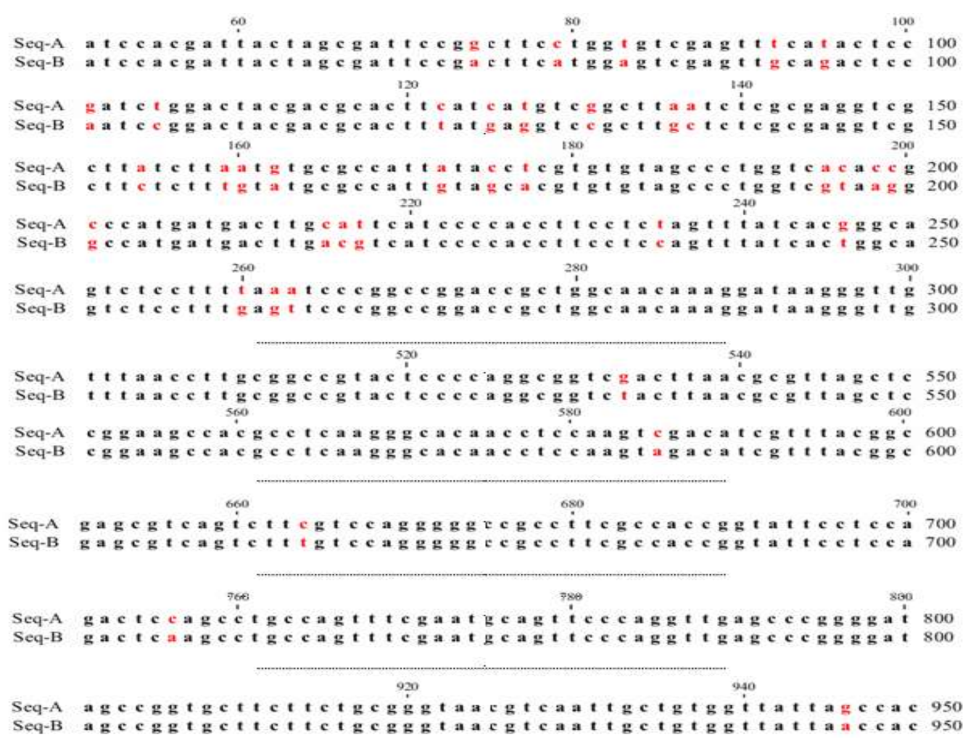


Fig. 4. Five regions of aligned 16S rDNA sequences of bacterial specie TY (Seq-A) and *S. enterica* subsp. enterica serovar Heidelberg str. B182 (Seq-B) showing 38 polymorphic nucleotides (in red colour)

bacterial species for which sequence data is not yet available in the GenBank database.

Screening of bacterial species ty for pathogenicity:

Bacterial species TY was found to relate closely with two different strains (B 182 & SL 476) of *S. enterica* subsp. enterica serovar Heidelberg strain B182, both of which are established to be pathogenic towards mammals (Bars et al *2012, Hoffmann* et al 2013). Congo red agar assay was performed to know whether the isolated specie was pathogenic or not. However, Bacterial specie TY produced only white colonies on Congo red agar medium (Fig. 5), which was suggestive of possible non-pathogenic nature of this bacterial species which indicate bacterial isolate *S. enterica* subsp. enterica strain TY was non-pathogenic thiamethoxam degrading bacteria. Besides this, biodegradation of different insecticides molecules by various species of *Bacillus* and *Pseudomonas* genera are well established but this is the first report on similar metabolization of any insecticide by species of *Salmonella*. Although, there are some other reports on *Salmonella* species which showed that this species can degrade such compounds which are explosive and toxic. Joseph *et al* (2006) observed that *Salmonella enterica* degrade ethanolamine (EA) is a sole source of carbon and nitrogen under aerobic, and anaerobic conditions. Acetaldehyde, an intermediate in ethanolamine degradation, is both volatile and toxic. Evidence had been presented that the primary function of the carboxysome (in *Salmonella*) encoded by *eut* is to minimize acetaldehyde loss and improve the efficiency of growth on EA. There is another report by Ederer et al (1997), according to which facultative enteric bacteria *Escherichia coli,* and *Salmonella typhimurium*, produced 4-amino-2,6-dinitrotoluene (ADNT), and accumulated less than stoichiometric amounts of 2,4-diamino-6-nitrotoluremovalene (DANT) from explosive 2,4,6-Trinitrotoluene (TNT). These previous studies have shown that *Salmonella* species can degrade toxic compounds, suggesting the broader metabolic capability of the specie.

Fig. 5. Screening of bacterial species TY (*S. enterica* strain TY) for pathogenicity produced only white colonies on Congo red agar medium

Effect of various cultural parameters on bacterial growth

Salmonella enterica subsp. *enterica* strain TY demonstrated optimal growth at 37°C, with maximum growth occurring between 2-4 days under shaking conditions (Fig. 6A and 6B). The strain exhibited effective growth over a pH range of 5.5-7.5, with the optimal pH at 6.5 (Fig. 6C). This suggests that TY is somewhat alkalophilic but can tolerate a range of pH levels. Therefore, further experiment was performed according to optimum parameters i.e at 37ºC in a medium of initial pH of 6.5 under shaking conditions.

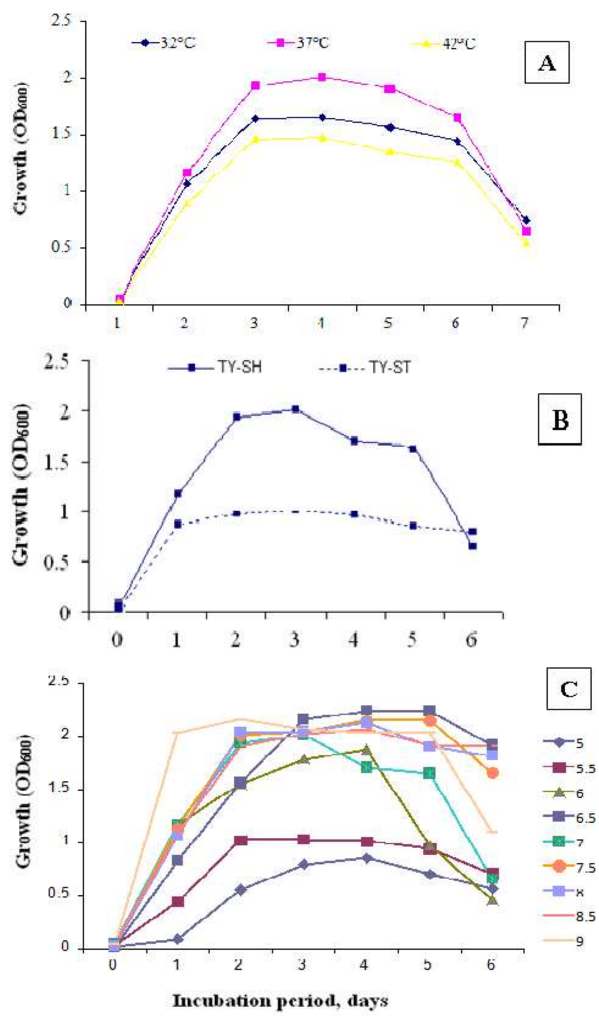


Fig. 6. Cell growth (OD_{600}) of different bacterial species as influenced by A- Incubation temperature, B- Aeration (shaking vs. stationary culturing) and C- Medium pH . TY- *S. enterica* strain TY, SH- Shaking conditions, ST- Stationary conditions

Effect of supplemented carbon and nitrogen sources on thiamethoxam degradation:

The prepared MSMT media raised with an optimum pH of 6.5 was inoculated with the bacterial inoculum and incubated @ 37ºC as described in material and methods. After 15 days of incubation, thiamethoxam degradation in uninoculated control treatments remained low (6.02-6.93%). Under unsupplemented conditions (C_0N_0), the cell growth of *S. enterica* subsp. enterica strain TY, remained low (OD_{600}= 0.484 to 0.510) but was associated with a maximum reduction in thiamethoxam (41.68%). The availability of additional nitrogen (C_0N_1) as well as carbon source (C_1N_1, C_1N_2) in the amended MSMT resulted in improved growth of the bacterial species (Table 4). However, this increase in growth due to the additional presence of carbon and nitrogen sources (C_0N_1, C_1N_1, and C_1N_2) was associated with a parallel decrease in thiamethoxam reduction by the bacterial isolate. Thus decline in thiamethoxam degradation as compared to unamended MSMT was enhanced in the presence of additional nitrogen ($C_0N_0 \rightarrow C_0N_1$) and further with the increase in the level of nitrogen in the presence of additional carbon ($C_1N_1 \rightarrow C_1N_2$). Though the study did not include analysis for degradation products of thiamethoxam, GLC chromatograms of culture extracts always showed only one peak specific to thiamethoxam only with a complete absence of peaks due to any possible degradation product of the same suggesting complete metabolization of this insecticide to metabolites that are not detectable by GLC. Thiamethoxam degradation by *S. enterica* subsp. enterica strain TY is repressed by the presence of easily available carbon and nitrogen sources and is stimulated by the absence of the same from the culture medium. It is also possible that enzymes involved in thiamethoxam metabolization are induced in the presence of thiamethoxam as the sole source of carbon and nitrogen causing higher degradation of the same in unamended media. A similar pattern of biodegradation in the presence of nitrogen and carbon followed by *B. aerophilus* strain IMBL 4.1, and *P. putida* strain IMBL 5.2 (Rana *et al* 2015). This phenomenon is typical of repressible metabolic pathways, reactions of which are inhibited by the presence of easily available nutrients for growth. The strain's ability to degrade thiamethoxam effectively in nutrient-limited conditions highlights its potential utility in contaminated environments.

Table 2. Statistical data on regression analysis and half-life for the dissipation of total thiamethoxam by isolated bacterial species in liquid cultures

Bacterial species	Regression equation *Y=a + bx (Y)*	Half-life (days)	Correlation coefficient *(R2)*
TA	3.68 + (-0.005x)	60.20	0.96
TB	3.67 + (-0.0073x)	41.23	0.80
TC	3.67 + (-0.0062x)	48.55	0.86
TD	3.69 + (-0.0094x)	32.02	0.93
TE	3.69 + (-0.0064x)	47.03	0.98
TF	3.69 + (-0.0027x)	91.48	0.95
TX	3.68 + (-0.0097x)	31.03	0.85
TY	3.64 + (-0.0027x)	28.13	0.93
TZ	3.68 + (-0.0069x)	43.62	0.97
Control	3.69 + (-0.0029x)	103.79	0.96

Table 3. Bacterial species producing maximum 16S rDNA homology with bacterial isolate TY as characterized by 100% query coverage, maximum score and lowest e-value (0.00)

Seq #	Species description	Max score	Identity	Gen Bank Acc. #
1.	*Salmonella. enterica* subsp. enterica serovar Heidelberg str. B182	1768	96%	CP003416.1
2.	*Salmonella enterica* subsp. enterica serovar Heidelberg str. SL476	1768	96%	CP001120.1
3.	*Salmonella. enterica* subsp. enterica serovar Heidelberg str. 41578	1768	96%	CP004086.1
4.	*Salmonella enterica* subsp. enterica serovar Paratyphi A str. AKU_12601 strain AKU12601 16S ribosomal RNA, complete sequence	1762	96%	NR_074935.1
5.	*Salmonella enterica* subsp. enterica serovar Paratyphi A str. ATCC 9150 strain ATCC 9150 16S ribosomal RNA, complete sequence	1762	96%	NR_074934.1
6.	*Salmonella enterica* subsp. enterica serovar Paratyphi C strain RKS4594 strain RKS4594 16S ribosomal RNA, complete sequence	1746	96%	NR_074899.1
7.	*Salmonella bongori*NCTC 12419 strain NCTC 12419 16S ribosomal RNA, complete sequence	1735	96%	NR_074888.1
8.	*Salmonella enterica* subsp. houtenae strain DSM 9221 16S ribosomal RNA, partial sequence	1735	96%	NR_044371.1
9.	*Salmonella enterica* subsp. enterica serovar Choleraesuis str. SC-B67 strain SC-B67 16S ribosomal RNA, complete sequence	1729	96%	NR_074800.1
10.	*Salmonella enterica* subsp. enterica serovar Typhi str. Ty2 strain Ty2 16S ribosomal RNA, complete sequence	1724	96%	NR_074799.1

Table 4. Effect of carbon and nitrogen sources on thiamethoxam degradation (%) by different bacterial specie after 15 days of incubation

Bacterial specie	CN level	Growth (OD_{600})	Thiamethoxam	
			Contents, µg ml^{-1}	% Reduction
Control	C_0N_0	-	45.89± 1.02	6.57
	C_0N_1	-	45.80±0.95	6.93
	C_1N_1	-	46.17±0.89	6.18
	C_1N_2	-	46.25±1.10	6.02
S. enterica	C_0N_0	0.484±0.012	28.70±0.75	41.68
	C_0N_1	0.867±0.019	29.62±0.79	39.81
	C_1N_1	1.210±0.029	29.97±0.65	39.10
	C_1N_2	1.284±0.032	31.35±0.78	36.29

Data is mean± SE of three replications each. Mean thiamethoxam concentration in uninoculated control at 0 day irrespective of treatment was estimated to be 49.21±0.86 µg ml^{-1}

Irrespective of treatment, mean OD_{600} was kept constant at 0.030±0.005 through use of uniform inoculation conditions.

Abbreviations are: C_0- No glucose; C_1- 0.1% glucose, N_0- No Nitrogen, N_1 and N_2- 0.1% and 0.2% ammonium sulphate, respectively. All media also contained ammonium ferric citrate at 0.001% level to serve as source of iron.

The number of microorganisms reported to degrade different pesticides but in this paper only thiamethoxam degrading microorganism discussed. Rana et al (2015) reported twelve bacterial strains of *Bacillus* and *Pseudomonas* which cause thiamethoxam reduction over a wide range of 20.88 to 45.28% after 15 days. Among them, two bacterial species *B. aerophilus* strain IMBL 4.1 (45.28%) and *P. putida* strain IMBL 5.2 (38.23%) caused the highest thiamethoxam biodegradation during 15 days periods of growth in the MSMT liquid culture. Rana and Gupta (2019) studied the persistence of thiamethoxam in clay loam soil for 56 days in laboratory conditions. They reported active biodegradation of thiamethoxam by *Bacillus aerophilus* strain IMBL 4.1. They also studied the half-life ($t_{1/2}$) in clay loam soil at different concentration (@ 25, 50, and 100 $mgkg^{-1}$) of thiamethoxam and found a reduction in half-life ($t_{1/2}$) (11.15, 11.58. and 12.54) as compared to half-life ($t_{1/2}$) in control (33.44, 37.63, and 37.63). Oanh and Duc (2023) showed that mix culture of *Phanerochaete* sp. Th1 and *Ensifer* sp. Th2 effectively degrade thiamethoxam in liquid media, maize straw, and soil, with the highest degradation rate observed in their mixed culture (*Phanerochaete* sp. Th1, *Ensifer* sp. Th2, and mixed culture has 0.53 ± 0.05, 0.74 ± 0.07, and 0.81 ± 0.08 mg/day degradation rates, respectively). They showed that *Phanerochaete* sp. Th1 excels in decomposing maize straw components, while *Ensifer* sp. Th2 efficiently handles Cl^{-} removal after initial dechlorination by the fungus. Xiang et al (2023) also demonstrates that immobilizing *Chryseobacterium* sp. H5 in polyvinyl alcohol (PVA)/sodium alginate (SA)/biochar beads significantly enhances the biodegradation of thiamethoxam, achieving up to 90.47% removal and 68.03% degradation rates. The approach also improves microbial tolerance to extreme conditions and provides valuable insights into the degradation pathways of thiamethoxam.Similarly, this study results also contribute to understanding the broader metabolic capabilities of *Salmonella* species. While *Salmonella* is not typically associated with pesticide degradation, strain TY's ability to metabolize thiamethoxam, combined with its non-pathogenic nature, opens new avenues for bioremediation research. The study demonstrates that *Salmonella enterica* subsp. *enterica* strain TY effectively degrades thiamethoxam under specific nutrient-limited conditions. The strain exhibited optimal growth at 37°C and pH 6.5, with significant degradation observed in unsupplemented media. Notably, the presence of easily available nitrogen and carbon sources suppressed thiamethoxam degradation, indicating a repressible metabolic pathway, while nutrient-limited conditions stimulated higher degradation rates. GLC analysis showed complete metabolization of thiamethoxam to undetectable products, suggesting that degradation pathways may produce metabolites not easily measured by conventional methods. These findings highlight the potential of strain TY for bioremediation applications in environments contaminated with thiamethoxam, particularly in scenarios where nutrient levels are low, allowing for the maximization of its degradation capabilities. Overall, this research contributes valuable insights into the microbial metabolism of insecticides and the conditions that optimize such processes for environmental remediation efforts.

CONCLUSIONS

This study has successfully isolated, and characterized a novel thiamethoxam-degrading bacterial strain, *S. enterica* subsp. *enterica* strain TY. This strain shows significant potential for bioremediation of thiamethoxam in contaminated environments. Further research into the specific metabolic pathways involved, and the development of optimized conditions for large-scale application could enhance the practical utility of this strain in environmental cleanup efforts. Biodegradation is the best way as it uses specific microorganism which has capabilities to degrade harmful compound along with this some of them have a broad spectrum of action on different pesticides. Thus, there is a need to know more about microbe's physiology, genetic behavior, and mechanism of action to enhance its biodegradation in less time and rapidly.

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Impact of Eco-Friendly PAU Fruit Fly Traps against Fruit Flies Infesting Guava under Central Punjab Conditions

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***Abstract*:** Guava (*Psidium guajava* L.) is one of the most important commercial fruits grown in Punjab. However, fruit flies, *Bactrocera* spp. are considered the key insect pests of guava causing heavy yield losses ranging from 10-100 per cent and quality degradation. Methyl eugenol based eco-friendly pheromone traps (PAU Fruit Fly Traps) were tested at farmer's fields in guava during 2023 and 2024 in the central Punjab. In the demonstrated technology, the fruit infestation was only 20.99 per cent while maximum percentage was recorded in untreated control (55.67 %). Similarly, yield was highest (88.06 q/ha) in technology demonstrated orchards in comparison to untreated control (83.69 q/ha). Similar trend was observed for maximum number of marketable fruits (365 fruits/plant) in the treated plots, as compared to 222 fruits/plant in untreated control. Mean fruit yield was also highest i.e. 57.8 kg/tree in technology demonstrated orchards as compared to untreated control with 37.8 kg/tree. After harvesting of crop, an average of 6899 fruit flies was collected from PAU fruit fly traps.

***Keywords*:** Frontline demonstrations, Fruit flies, Guava, Pheromone traps, Yield

Guava (*Psidium guajava* L.) occupies an area of 3.10 lakh ha with a production of 4469 metric tonnes in India (DAC&FW 2020-21), whereas in Punjab, it covers 12.173 thousand hectares with yield of 276685 kg/ha and productivity of 227.29 thousand metric tonnes (Anonymous 2024). Rainy season guava fruits are severely infested by fruit flies. Fruit flies are one of the most important pests of fruits and vegetables because of their effects on the crop, environment, society and economy. *Bactrocera dorsalis* and *B. zonata* are the most damaging fruit flies and major constraints in successful guava cultivation and results in quality degradation, decreased fruit production and heavy yield losses (10-100 per cent) (Singh and Sharma 2013, Singh et al 2020, Mohanpuria et al 2021, Yue et al 2023 a,b). Fruit flies are highly challenging to control as they are multivoltine, polyphagous, highly mobile adults, and unexposed during all developmental phases. Adults are most vulnerable as eggs and maggots are shielded in the host tissues and are non responsive to most of the insecticidal treatments (Verghese et al 2012). So, in the present scenario, an eco-friendly approach to manage these fruit flies is currently necessary as the use of the insecticides disturbs the ecosystem and poses number of risks. As an alternate strategy, male annihilation technique (MAT) is widely used in which methyl eugenol which is primarily a para-pheromone, is combined with an insecticide that infused on a wooden substrate in a plastic bottle trap. These traps are very effective in the management of several *Bactrocera* spp. (Manrakhan et al 2014, Shelly et al 2014, Bhowmik et al 2015, Singh et al 2015). In this context, eco-friendly technology of PAU Fruit Fly Traps was tested at farmer's fields by Krishi Vigyan Kendra, Kapurthala, Punjab (India) in guava orchards during 2023 and 2024 with an objective to manage these fruits flies effectively in the rainy season crop.

MATERIAL AND METHODS

Krishi Vigyan Kendra, Kapurthala conducted demonstrations over five locations (Nadala (N 31.5458˚ E 75.4388˚), Subhanpur (N 31.5424156˚ E 75.4355317˚), Mand dhillwan (N 31.4972492˚ E74.3333884˚, Mand Kuka (N31.586304˚ E75.450432˚ and Feroz Sangwal (N 31.627˚ E 75.5015˚) of Dhillwan and Nadala blocks of district Kapurthala, Punjab (India) to manage the infestation of fruit flies in rainy season guava during 2023 and 2024 on an area of 2.5 ha. Sixteen PAU Fruit Fly Traps per 0.40 ha were fixed in each guava orchard along with an untreated control area. The baited bottles were hanged with the trees at equidistance. The traps were fixed in the first week of the July till fruit harvesting was over. PAU Fruit Fly Traps were installed in guava orchards to assess losses to the fruits and to measure the efficacy of different local and recommended management options at weekly intervals. The traps used in MAT technique consisted of immersing water absorbable plywood blocks (7.5 cm x 6.0 cm x 2.0 cm) in a solution of ethyl alcohol, methyl eugenol (98%) and malathion mixed in a glass jar in the ratio of 6:4:1 (v/v) for 72 h so that the solution was properly absorbed in the plywood blocks (Singh and Sharma 2013). Bottles were fixed/ hanged at a height of 1-1.5 m from ground level, depending upon the height of tree, at a place receiving no direct sunlight. The selected tress were demarked with red coloured reflecting tape for easy an easy identification of traps. The lower cut portion of bottle (lid) was removed and all the fruit flies trapped in bottle were collected in carry bag after every seven days and then, the lid was again re-fixed. The carry bags were labelled and fruit flies trapped/trap were counted. Impact of traps on the number of marketable fruits was also assessed by counting number of marketable fruits from five trees (Singh et al 2014). In both treated (16 traps per 0.40 ha) and untreated control areas, a sample of 50 guava fruits was collected at random from each treatment at weekly intervals. The fruits were categorized as infested (based on oviposition punctures), fallen infested fruits, or healthy fruits. The percentage of fruit infestation was then calculated. Marketable yield was worked out by using data on per cent fruit damage on weight basis. Impact on the quality of marketable fruits and yield was also assessed from 5 trees at full maturity (Singh et al 2014). The obtained data was statistically analyzed and coefficient of variation were also calculated.

RESULTS AND DISCUSSION

Population of fruit flies captured in fruit traps: The incidence of fruit flies started from 2nd week of July both in 2023 and 2024 (28th SMW). Results revealed that mean male population capture of 500.26 fruit flies/trap/week was observed in 28th SMW from different locations of Kapurthala district (Table 1). After that, the population increased rapidly reaching its peak with weekly mean trap catches of 1132.1 fruit flies/trap/week during the second week of August (32nd SMW), when the trees was at the maximum fruiting stage.

Thereafter, the trap catches of fruit fly declined gradually and the lowest mean trap catches of 382.46 fruit flies/trap/week during the last week of September (37th standard week) when the crop was to be last harvested (Table 1). The pooled mean revealed that the maximum fruit flies were captured from Feroz Sangowal (7509), followed by Mand Kuka (7448), Nadala (6625) and Mand Dhillwan (7448) whereas, the least population was captured in Subhanpur (6338) . First criteria to understand the behaviour of any pest is the record of population monitoring data, so that they can be effectively controlled by devising appropriate management strategies before reaching their peak potential to damage the crop. Similarly, in this study, population of fruit flies fluctuated widely from very low to peak level in both years of study depending on the stage of the crop and weather conditions.

During both years, initial population of fruit flies was observed at fruit set up stage on the 28th SMW, whereas peak population of fruit flies was observed when the fruits were at peak fruiting period, *i.e.* 31st and 32nd SMW. Highest population was recorded when the crop reaches its maximum fruiting period during 32nd SMW and subsequently, there was decrease in the population as fruits were harvested. Fazlullah et al (2015) also reported that fruit fly population was maximum before ripening of fruits and then decrease afterwards. Vignesh et al (2020) reported that population of guava fruit flies *B. correcta* and *B. dorsalis* reached its peak in August. Hence, it is vividly confirmed that activity of fruit flies was maximum in the month of July and August. Vargas et al (2015) and Math et al (2018). Singh and Sharma (2013) also revealed that 16 traps/acre trapped significantly more population of males of *B. dorsalis* and *B. zonata.* Bajaj and Singh (2018) also highlighted the importance of PAU fruit fly traps in capturing significantly more fruit flies in comparison to other cylindrical spherical traps.

The maximum percentage of fruit infestation was observed in untreated control *i.e.* 55.67 per cent as compared to 20.49 per cent in technology demonstrated orchards. Kaur et al (2016) also reported that 25.4 per cent of fruits in guava orchards were infested when fruit fly traps were used compared to 81.3 per cent in the control orchards. Marketable fruits in technology demonstrated orchards were higher (362 fruits/tree) in comparison to untreated orchards (222 fruits/tree). Singh et al (2014) assessed that successful eco-friendly management of fruit flies in guava can be achieved by placing PAU fruit fly traps @ 16 traps per acre during the first

Table 1. Fruit flies trap catch during different weeks per trap in different blocks of Kapurthala (2023 & 2024)

Name of blocks	SMW* 28	SMW 29	SMW 30	SMW 31	SMW 32	SMW 33	SMW 34	SMW 35	SMW 36	SMW 37	Total catch
Nadala	467.3	539.5	675.3	684.9	1056.5	965.4	811.5	624.5	472.5	327.6	6625
Subhanpur	464.5	529.5	616.5	794.4	1061.5	897.2	642.8	516.8	462.9	352.3	6338
Mand Dhillwan	456.5	489.5	716.4	780.5	1092.5	889.6	719.2	603.8	459.8	366.1	6573
Mand Kuka	528.5	574.5	787.5	995.5	1198.5	869.4	829.1	693.4	542.8	429.2	7448
Feroz Sangowal	584.5	619.5	686.3	784.4	1251.5	1007.2	849.5	716.8	572.5	437.1	7509
Mean	500.26	550.5	696.4	807.94	1132.1	925.76	770.42	631.06	502.1	382.46	6899

*Standard meteorological weeks
**16 PAU Fruit fly traps per 0.40 ha

Table 2. Impact of PAU Fruit fly traps on percent fruit infestation, marketable fruits and yield parameters in guava orchards

Year (2023 & 2024)	Per cent fruit infestation		Marketable fruits (number)		Mean fruit yield/tree (kg/tree)		Yield (q/ha)	
Blocks	Control	*DP	Control	DP	Control	DP	Control	DP
Nadala	62.67	23.17	218.0	376.5	37.53	55.0	17.08	27.32
Subhanpur	59.25	18.06	227.0	358.0	42.58	62.05	19.96	28.61
Mand Dhillwan	60.59	28.26	224.0	362.5	37.54	65.5	17.37	22.92
Mand Kuka	50.33	16.13	214.5	365.0	32.4	55.5	16.61	27.66
Feroz Sangowal	45.51	16.86	226.0	348.0	38.97	50.95	18.02	27.95
Average	55.67	20.49	222.0	362.0	37.80	57.8	17.81	26.89

*Demonstrated practice

week of July in order to obtain a higher number of marketable fruits. The cumulated mean yield was again highest (26.89 q/ha) in technology demonstrated orchards in comparison to untreated control (17.81 q/ha). The present study is further strongly supported with the findings of Kaur et al (2016) and Sharma et al (2022) where maximum number of marketable fruits/tree and mean fruit yield was observed in orchards having PAU Fruit Fly Traps as compared to untreated plots.

CONCLUSIONS

The fruit flies cause significant damage to guava fruits. Use of chemical insecticides for its control is costly as well as usually ineffective also. The demonstrated technology of PAU fruit fly traps is highly effective, especially when installed @ 16 traps per 0.40 ha in the first week of July, during the pre-oviposition stage. Use of these pheromone traps, along with integrated management strategies such as collection and burying infested and fallen fruits, tillage around the trees in the fields during summer, proved a very effective approach. Regular monitoring and analysis during the growing season showed a clear reduction in infestation rates also demonstrating the effectiveness of PAU fruit fly traps. This eco-friendly technology also offers several advantages; lower labour costs, affordability, safety compared to chemical insecticides, residue-free fruits, and no adverse effects on natural enemies, human health, and the environment. Hence, to achieve fruit fly suppression on a large scale, there should be more emphasis on promotion and adoption of 'PAU Fruit Fly Traps by creating mass awareness among the large number of fruit growers by demonstrating this technology.

AUTHORS' CONTRIBUTION

Dr Suman Kumari conducted the research work, analyzed the data; Dr Harinder Singh provided critical feedback and revised the manuscript and Dr Sandeep Singh helped in planning the experimentation and drafting the manuscript. All authors read, provided critical feedback, and approved the manuscript.

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Management of *Rhyzopertha dominica* (Fab.) by Hermetic Bags and Impact on Quality Attributes of Stored Wheat

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Abstract: Wheat is one of the most important cereal crop, undergoes huge economic losses during storage by insect-pest infestations especially *Rhyzopertha dominica*. Management with chemical insecticides led to development of resistance among insect-pests of stored grains including *R. dominica*, which threatens its status as a reliable fumigant. So, it arises the need to explore some alternative insect-pest control. Keeping in view for exploring the alternatives, hermetic storage bags (HSBs) viz. HSB-1, HSB-2, HSB-3 were compared against traditional storage bags viz. Polypropylene woven and Jute bag to manage *R. dominica* under natural and artificial infestation conditions in stored wheat for a period of 180 days. The results revealed that no F_1 progeny emergence of *R. dominica* was observed under natural condition, while little emergence till 90 days of storage under artificial condition in all the hermetic bags. On comparing with traditional PP woven and jute bags, emergence and multiplication of *R. dominica* was observed throughout the storage period. Further, all the hermetic storage bags showed very less grain damage, weight loss along with maintaining grain moisture content and germination rate of wheat when compared to traditional bags under both the conditions throughout the storage period. Among gas exchanges, hermetic bags had maximum $CO_2$with more depleted level of O_2, while atmospheric level of CO_2 and $O_2$was observed in traditional bags. Comparison of all the hermetic bags showed HSB-3 is the best option to manage *R. dominica* along with maintaining other quality parameters with least gas exchange for long term storage of wheat. Thus, hermetic bags offer agricultural businesses a dependable, affordable, and environmentally responsible alternative that helps them protect their harvests and increase their profitability.

Keywords: Wheat**,** Hermetic bags, Storage, *Rhyzopertha dominica,* Gaseous content

Wheat crop is widely cultivated as a cool season annual crop which contributes about 35% of total food grain production of the country. In India, it was sown on an area of 305.0 lakh hectares with a production and productivity of 106.8 million tonnes and 35.07 quintals per hectare, respectively, during 2021-22 (Anonymous 2021). Wheat productivity per unit area has increased because of various practices which has further intensified concern for its proper storage. As the storage of wheat has been affected by various biotic and abiotic factors. Among various biotic factors, insect-pests played vital role for the post- harvest losses and among different stored grains, wheat found to be 2.5% more susceptible to be damaged by insects (Vishwakarma et al 2019). These losses can be reduced by integration of scientific storage procedures with ecofriendly natural materials.

Rhyzopertha dominica (Fab.) (Coleoptera: Bostrichidae) is the major threatening insects with cosmopolitan distribution pattern. It is primary insect-pest, which is highly destructive cause quantitative damage to stored wheat, corn and rice. Both the larval and adult stages of *R. dominica* cause damage, which lead to severe weight loss, bad odor due to insect secretions, reduction in nutrient contents and germination ability of the stored wheat. Use of chemicals *i.e.* synthetic insecticides and fumigants have been a popular strategy in developing countries for preventing insect-pests in grain during storage. The extensive use of phosphine has led to development of resistance among insect-pests of stored grains including *R. dominica* (Collins et al 2017), which threatens its status as a reliable fumigant.

Thus, an alternative is required to manage *R. dominica* in stored wheat to avoid post-harvest losses. Hermetic bags are the game changer in grain storage. Grain storage in these airtight, moisture-resistant bags create a controlled environment that protects grains from external environment (Lane and Woloshuk 2017). Nevertheless, there aren't many thorough research conducted in India on how the hermetic bags stored wheat affect insect-pests. Therefore, a study was conducted to compare the effectiveness of hermetic bags used globally such as Vestegaard, Ecotact, Save Grain against traditional storage bags *i.e.* Polypropylene (PP) woven and jute bag (JB) for storage of wheat by managing *R. dominica* as well as maintaining quality parameters of wheat under two conditions *i.e.* natural and artificial. Our research sheds light on how these kinds of bags for packing can assist farmers make better choice for preserving wheat and lowering post-harvest losses by maintaining its quality.

MATERIAL AND METHODS

Storage bags and description : The present investigations were conducted in the laboratory of Department of Processing and Food Engineering, Punjab Agricultural University (PAU), Ludhiana to study the effectiveness of hermetic storage bags (HSB) *i.e.* Vestergaard (HSB-1), Save Grain (HSB-2) and Ecotact (HSB-3) against two traditional storage bags like Polypropylene woven (PPW) and Jute bag (JB). The brand, composition, thickness and bag supplier are included in Table 1. All bags were available in 50 kg capacity except PPW and JB having 10 kg capacity. However, for the study purpose the smaller units (10 kg capacity) were modified without altering the properties (Paudyal et al 2017).

Grain sample preparation: The wheat grain var. PBW 824 (locally popular in Punjab, India), procured from Director (Seeds) Punjab Agricultural University, Ludhiana. Wheat grains (300 kg) were kept in metallic drum (1 tonne capacity) and treated with the aluminum phosphide @ 1 tablet of 3g in the laboratory of Department of Processing and Food Engineering, Punjab Agricultural University, Ludhiana. The drum was kept closed till 7 days for proper fumigation to remove any hidden insect-pest infestation for further experimentation. The wheat grains of 200 kg were kept in metallic drum without giving any disinfestation treatment.

Rearing of the test insect: Test insect (*Rhyzopertha dominica*) were collected from naturally infested farmer's field. The culture was reared on disinfested wheat grains filled up to 1/3rd capacity of plastic jars (500 ml), covered with muslin cloth and tightened with rubber band, to ensure ventilation avoiding the escape of insects. These jars were kept in BOD incubator (27±2°C and relative humidity 75±5%) for further multiplication. After one month, *R. dominica* adults were shifted from old jars to new jars to avoid any kind of fungal infection. Pure culture was used to conduct the experiments.

Experimental set up and sampling: The experimental plan was designed by factorial CRD with five treatments (in quadruple) *viz.* HSB-1, HSB-2, HSB-3, PPW and JB with two conditions *i.e.* un-infested (natural condition) and infested (artificial condition). Each bag of 10 kg capacity was filled with wheat to its optimum storage capacity, including the closure space. Wheat grains were filled in various bags without giving any disinfestation treatment under natural condition. While, the freshly emerged mixed adult population of *R. dominica* @ 10 insects / kg grains were released in each bag under artificial condition. After filling the bags with wheat grains, the bags were sealed air-tight using nylon tags. The rubber septa were fixed on all bags for measuring the CO_2 and O_2 concentrations. All these bags were further packed in jute bag liners to get them protected from any kind of damage. The samples were then stacked on pallets maintaining the stack height of 4.00 feet and away from 1 metre from wall having storage room mean temperature varied from 25.1-32.9°C and relative humidity varied from 39-74% throughout the storage studies (May to October 2022). The sample size of 500g were drawn every month for recording quality parameters *i.e.* F_1 adult emergence (number) insect count was made from 100 g sample (Syed et al 2022) , grain damage (%), weight loss (%) (Boxall, 2002), grain moisture (%)(AOAC, 2016), germination (%) (ISTA, 2015) and CO_2 & O_2 (%) by using headspace gas analyser (GS3/P, U.K.) to measure concentrations till 180 days. The bags were discarded after taking the observations.

RESULTS AND DISCUSSION

Effect of various storage bags on adult emergence: The importance of HSBs in relation to the adult emergence of *R. dominica* was evident when comparing natural and artificial infestation conditions. No F_1 progeny emergence was observed naturally, there was a subtle emergence (≤1.66 adults) within the initial 90 days of storage under artificial conditions. Adult emergence rates remained consistent in all HSBs throughout the storage period, regardless of whether the conditions were natural or artificial except till 90 days under artificial condition. However, the emergence patterns observed in PPW and JB were noteworthy. JB displayed the highest emergence numbers (16.75 adults) under artificial condition, while 14.00 adults under natural condition by the

Table 1. Detail of different bags used in study

Type of bags	Description of bags	Thickness (µm)	Capacity (Kg)	Make
HSB-1	Pesticide free, woven PP structurally reinforced with a laminated layer and hermetic film with a high quality gas barrier layer	30	50	Vestergaard
HSB-2	Pesticide free, single multilayer polymeric bags with food grade recyclable plastic resins	82	50	Ecotact
HSB-3	Pesticide free, single multilayer polymeric bags with advanced technology and gas barrier polymer inside	80	50	Savegrains
PPW	-	-	10	Local market, Ludhiana
JB (Untreated control)	-	-	10	Local market, Ludhiana

180th day of storage. In contrast, PPW bag showed slightly lower infestation levels compared to JB, with emergences of 9.75 and 12.00 adults in number under natural and artificial conditions, respectively (Table 2). Hermetic storage bags effectively hindered damage by pulse beetles under both artificial and natural infestation conditions through mechanisms such as insect reproduction prevention and lack of aeration (Yewle et al 2020, Mutungi et al 2014). A hermetic environment, as emphasized by Kiobia et al (2020), disrupts insect development, metamorphosis, and reproduction due to oxygen deprivation.

Effect of various storage bags on quality parameters: The degree of insect infestation closely correlates with grain damage and losses during storage, as highlighted in studies by Yewle et al (2021) and Akrofi et al (2023). Minimal grain damage percentages (≤ 0.87) were observed across all hermetic storage bags (HSBs), significantly differing from PPW and JB under both natural and artificial conditions across various storage intervals. Among all HSBs, HSB-3 exhibited the lowest grain damage, with values of ≤0.65 under natural condition and ≤1.61 under artificial condition. Conversely, JB showed the highest grain damage, reaching 31.42 and 51.85% under natural and artificial conditions, respectively (Table 3). Hermetic storage bags demonstrated superior efficacy in minimizing grain weight loss when storing wheat, with HSB-3 exhibiting the least loss (≤0.15), followed by HSB-2 (≤0.19) and HSB-1 (≤0.25) under natural condition. This trend persisted under artificial condition, albeit with slightly higher losses. HSB-3 proved to be the most efficient, with ≤0.50% grain weight loss. In contrast, JB-stored wheat experienced maximum grain weight loss (≤25.63 and 39.23), followed by PPW (≤14.74 and 26.19) under natural and artificial conditions, respectively, over a 180-days of storage period. PPW and JB, being non-airtight, facilitate gaseous exchange, aligning with findings from Akrofi et al (2023).

The study highlighted the substantial decrease in grain damage when wheat was stored in hermetic bags under natural condition, contrasting with significant damage seen in PPW and JB over a six-month storage period. Anankware (2013) investigated the impact of various storage bags on *S. zeamais* and *P. truncatus* in maize grains, finding that prolonged storage in conventional bags significantly increased insect-induced damage. This supports earlier research by Atta et al (2020), Darfour and Rosentrater (2020), Yewle et al (2021), and Saini et al (2022), emphasizing the effectiveness of hermetic bags in controlling pulse beetle or bruchid damage compared to conventional bags. Wasala et al (2016) observed increased grain weight loss due to insect pests during the 30 to 150 days storage period. Study similarly showed significant weight loss in both infested and un-infested non-hermetic bags, while no significant difference was found among hermetic bags.

The moisture content of wheat stored in all HSBs was consistent and minimal with HSB-3 exhibiting the lowest moisture content (≤11.37 and 11.38 %) under natural and artificial conditions, respectively. Conversely, grain moisture was highest in JB-stored wheat (≤16.00 and 16.11%), followed by PPW bags (≤14.45 and 14.48%) under natural and artificial conditions, respectively. The HSBs maintained favourable moisture levels when compared with initial moisture (11.34%), making them suitable for wheat storage. The hermetic bags outperformed ordinary bags in retaining moisture content consistently across different storage conditions, consistent with previous findings (Tubbs et al 2016, Bhandari et al 2018, Yewle et al 2021) was associated

Table 2. Effect of different bags on adult emergence in stored wheat

Storage conditions		Different bags	Storage (Days)					
			30	60	90	120	150	180
Adult emergence (number)	Natural (Un-infested)	HSG-1	0.00^{l}	0.00^{l}	0.00^{l}	0.00^{l}	0.00^{l}	0.00^{l}
		HSG-2	0.00^{l}	0.00^{l}	0.00^{l}	0.00^{l}	0.00^{l}	0.00^{l}
		HSG-3	0.00^{l}	0.00^{l}	0.00^{l}	0.00^{l}	0.00^{l}	0.00^{l}
		PPW	1.50^{de}	3.25^{gh}	3.75^{gh}	3.50^{gh}	5.50^{g}	9.75^{cd}
		JB	1.50^{de}	5.25^{g}	3.75^{cd}	5.50^{g}	9.50^{cd}	14.00^{b}
	Artificial (Infested)	HSG-1	1.66^{i}	1.33^{ij}	1.33^{ij}	0.00^{l}	0.00^{l}	0.00^{l}
		HSG-2	1.33^{ij}	1.33^{ij}	1.00^{j}	0.00^{l}	0.00^{l}	0.00^{l}
		HSG-3	1.00^{j}	1.00^{j}	0.66^{k}	0.00^{l}	0.00^{l}	0.00^{l}
		PPW	2.50^{h}	4.25^{gh}	7.75^{de}	9.50^{cd}	10.50^{de}	12.00^{b}
		JB	5.25^{g}	7.25^{ef}	11.25^{bc}	13.25^{b}	14.75^{b}	16.75^{a}

Mean values followed with different superscripts for different parameters significantly differ ($p<0.05$) using Tukey's test
At zero day of storage: No adult emergence, no grain damage, no weight loss

Table 3. Effect of different bags on quality parameters of stored wheat

Storage conditions		Different bags	Storage (Days)					
			30	60	90	120	150	180
Grain damage (%)	Natural (Un-infested)	HSG-1	0.82^{n}	0.85^{n}	0.87^{n}	0.85^{n}	0.87^{n}	0.83^{n}
		HSG-2	0.67^{o}	0.67^{o}	0.62^{o}	0.62^{o}	0.65^{o}	0.62^{o}
		HSG-3	0.63^{o}	0.60^{o}	0.65^{o}	0.60^{o}	0.62^{o}	0.65^{o}
		PPW	1.42^{m}	3.60^{k}	7.33^{i}	10.32^{h}	15.07^{g}	20.75^{e}
		JB	1.80^{m}	4.27^{j}	9.50^{h}	13.62^{g}	22.87^{e}	31.42^{c}
	Artificial (Infested)	HSG-1	2.45^{l}	2.68^{l}	2.69^{l}	2.66^{l}	2.65^{l}	2.64^{l}
		HSG-2	1.73^{m}	1.70^{m}	1.65^{m}	1.63^{m}	1.62^{m}	1.62^{m}
		HSG-3	1.61^{m}	1.60^{m}	1.55^{m}	1.56^{m}	1.53^{m}	1.52^{m}
		PPW	2.82^{l}	4.85^{j}	10.40^{h}	19.22^{f}	26.65^{d}	37.27^{c}
		JB	3.22^{k}	6.32^{i}	13.17^{g}	22.10^{e}	39.20^{b}	51.85^{a}
Weight loss (%)	Natural (Un-infested)	HSG-1	0.21^{mn}	0.23^{mn}	0.25^{mn}	0.22^{mn}	0.25^{mn}	0.23^{mn}
		HSG-2	0.19^{n}	0.19^{n}	0.15^{n}	0.14^{n}	0.15^{n}	0.13^{n}
		HSG-3	0.15^{n}	0.13^{n}	0.14^{n}	0.12^{n}	0.13^{n}	0.14^{n}
		PPW	0.37^{m}	1.32^{k}	3.27^{i}	5.43^{h}	9.12^{g}	14.74^{e}
		JB	0.47^{m}	1.69^{jk}	4.75^{f}	8.96^{d}	16.85^{b}	25.63^{a}
	Artificial (Infested)	HSG-1	0.71^{l}	0.82^{l}	0.83^{l}	0.80^{l}	0.80^{l}	0.78^{l}
		HSG-2	0.56^{m}	0.54^{m}	0.53^{m}	0.50^{m}	0.50^{m}	0.50^{m}
		HSG-3	0.50^{m}	0.50^{m}	0.45^{m}	0.46^{m}	0.40^{m}	0.40^{m}
		PPW	1.01^{k}	2.22^{j}	6.53^{h}	12.47^{f}	18.01^{d}	26.19^{c}
		JB	1.39^{k}	3.48^{i}	8.90^{g}	16.12^{e}	27.54^{b}	39.23^{a}
Grain moisture (%)	Natural (Un-infested)	HSG-1	11.38^{nop}	11.47^{lmno}	11.42^{lmno}	11.47^{lmno}	11.48^{lmno}	11.48^{lmno}
		HSG-2	11.35^{nop}	11.37^{nop}	11.34^{nop}	11.38^{mop}	11.43^{lmno}	11.41^{lmno}
		HSG-3	11.32^{op}	11.36^{nop}	11.34^{nop}	11.35^{nop}	11.33^{nop}	11.37^{nop}
		PPW	11.52^{klmn}	11.95^{j}	12.67^{h}	13.17^{g}	13.90^{e}	14.45^{d}
		JB	12.40^{i}	13.70^{f}	14.52^{d}	14.87^{c}	15.47^{b}	16.00^{a}
	Artificial (Infested)	HSG-1	11.40^{lmno}	11.47^{lmno}	11.45^{lmno}	11.50^{lmno}	11.49^{lmno}	11.52^{klmn}
		HSG-2	11.39^{nop}	11.38^{nop}	11.40^{lmno}	11.38^{mop}	11.4^{lmno}	11.42^{lmno}
		HSG-3	11.36^{nop}	11.37^{nop}	11.38^{nop}	11.35^{nop}	11.37^{nop}	11.38^{nop}
		PPW	11.51^{klmn}	12.00^{i}	12.77^{h}	13.19^{g}	13.95^{e}	14.48^{d}
		JB	12.42^{i}	13.81^{f}	14.61^{d}	14.92^{c}	15.51^{b}	16.11^{a}
Seed germination (%)	Natural (Un-infested)	HSG-1	89.75^{a}	89.50^{a}	89.25^{a}	89.50^{a}	89.25^{a}	89.25
		HSG-2	90.00^{a}	89.50^{a}	89.50^{a}	89.25^{a}	90.00^{a}	89.25^{a}
		HSG-3	90.25^{a}	90.25^{a}	89.75^{a}	90.00^{a}	89.50^{a}	90.50^{a}
		PPW	89.75^{a}	85.50^{b}	80.00^{d}	76.25^{e}	73.25^{f}	69.75^{g}
		JB	88.50^{a}	83.50^{c}	78.25^{d}	71.25^{g}	67.25^{h}	62.00^{i}
	Artificial (Infested)	HSG-1	89.00^{a}	89.00^{a}	88.50^{a}	88.75^{a}	89.25^{a}	89.00^{a}
		HSG-2	89.25^{a}	89.75^{a}	89.00^{a}	89.00^{a}	89.00^{a}	89.25^{a}
		HSG-3	89.75^{a}	89.50^{a}	89.32^{a}	89.52^{a}	89.50^{a}	89.37^{a}
		PPW	88.27^{a}	83.00^{c}	76.50^{e}	68.50^{g}	61.00^{i}	51.00^{k}
		JB	87.25^{a}	80.00^{d}	73.50^{f}	66.50^{h}	53.75^{k}	46.25^{l}

Mean values followed with different superscripts for different parameters significantly differ ($p<0.05$) using Tukey's test
At zero day of storage: seed germination-90.25%, grain moisture-11.34%

with reduced metabolic activity of insects (Mutambuki et al 2019). The conventional bags exhibited significant fluctuations in moisture content, particularly observed in PPW and JB, where moisture levels ranged from 11.52 to 14.45% and 11.51 to 14.48% under natural and artificial conditions, respectively, over a 30-180 day storage period. This variability in moisture content in conventional bags was also reported by Afzal et al (2020) which may be attributed to fungal growth on insect-injured grains.

HSB-3 emerged as the most effective in promoting maximum germination in stored wheat, with rates reaching ≤90.50% and 89.75% under natural and artificial conditions, respectively, statistically comparable to other HSBs and storage periods. Interestingly, the germination rate at day zero stood at a robust 90.25%, statistically similar to all three hermetic bags. Conversely, germination rates were lower in jute and PPW bags, with the most significant reduction observed in jute bags (62.00 and 46.25%) under natural and artificial conditions, respectively after 180 days of storage, followed by PPW bags. Samples stored in hermetic bags consistently exhibited higher germination rates compared to PPW and jute bags, consistent with findings by Yewle et al (2021). The germination was impaired in PPW and JBs under both conditions, with more pronounced reductions in germination observed under artificial conditions compared to natural conditions. The study unequivocally demonstrated that germination rates varied significantly depending on storage conditions and bag types used, aligning with findings by Abbas et al (2018), who reported no germination losses when grains were stored in hermetic bags. Similarly, Awal et al (2017) found that rice stored in PICS and GrainPro bags outperformed other conventional storage structures in terms of weight and germination losses. The use of hermetic bags to preserve seed quality and ensure successful storage has been consistently supported by previous studies, including by Abbas et al (2018), Likhayo et al (2018) and Afzal et al (2020).

Table 4. Effect of different bags on carbon dioxide and oxygen concentration in stored wheat

Storage conditions	Different bags	Storage (Days)					
		30	60	90	120	150	180
Natural (Un-infested)	CO_2 (%)						
	HSG-1	3.70^{l}	5.17^{jk}	6.27^{ghi}	7.00^{fg}	7.72^{ef}	9.34^{bc}
	HSG-2	4.57^{kl}	5.37^{ijk}	6.49^{gh}	7.28^{efg}	8.00^{de}	9.55^{bc}
	HSG-3	5.73^{hij}	7.00^{fg}	8.96^{cd}	9.23^{bc}	9.96^{b}	12.18^{a}
	PPW	0.04^{m}	0.04^{m}	0.04^{m}	0.04^{m}	0.04^{m}	0.04^{m}
	JB	0.04^{m}	0.04^{m}	0.04^{m}	0.04^{m}	0.04^{m}	0.04^{m}
	O_2 (%)						
	HSG-1	20.62^{a}	19.90^{b}	18.97^{c}	15.31^{f}	12.65^{h}	11.04^{k}
	HSG-2	19.22^{c}	16.85^{e}	14.68^{g}	12.91^{h}	12.35^{i}	10.79^{k}
	HSG-3	20.85^{a}	18.08^{d}	15.47^{f}	12.83^{h}	11.77^{j}	10.11^{l}
	PPW	20.90^{a}	20.90^{a}	20.90^{a}	20.90^{a}	20.90^{a}	20.90^{a}
	JB	20.90^{a}	20.90^{a}	20.90^{a}	20.90^{a}	20.90^{a}	20.90^{a}
Artificial (Infested)	CO_2 (%)						
	HSG-1	5.78^{kl}	7.65^{j}	8.52^{ij}	10.26^{gh}	11.85^{ef}	13.72^{cd}
	HSG-2	4.68^{l}	7.72^{j}	9.55^{hi}	11.86^{ef}	13.66^{cd}	15.58^{b}
	HSG-3	4.96^{kl}	6.12^{k}	11.25^{fg}	12.69^{de}	14.65^{bc}	17.97^{a}
	PPW	0.04^{m}	0.04^{m}	0.04^{m}	0.04^{m}	0.04^{m}	0.04^{m}
	JB	0.04^{m}	0.04^{m}	0.04^{m}	0.04^{m}	0.04^{m}	0.04^{m}
	O_2 (%)						
	HSG-1	20.34^{a}	17.03^{b}	12.52^{d}	9.95^{f}	6.47^{ghi}	6.07^{hij}
	HSG-2	20.90^{a}	17.56^{b}	12.45^{d}	9.07^{fg}	6.08^{hij}	5.89^{ijk}
	HSG-3	20.60^{a}	15.15^{c}	11.05^{e}	6.58^{gh}	4.86^{jk}	4.13^{k}
	PPW	20.90^{a}	20.90^{a}	20.90^{a}	20.90^{a}	20.90^{a}	20.90^{a}
	JB	20.90^{a}	20.90^{a}	20.90^{a}	20.90^{a}	20.90^{a}	20.90^{a}

Mean values followed with different superscripts for different parameters significantly differ ($p<0.05$) using Tukey's test
At zero day of storage: concentration of CO_2: 0.04% and O_2: 21.00%

HSB-3 exhibited notable differences in CO_2 and O_2 levels compared to other HSBs. Maximum CO_2 level was recorded in HSB-3, reaching ≤ 12.18% and ≤ 17.97% under natural and artificial conditions, respectively. Conversely, there was a significant decrease in O_2 level in HSB-3, with reductions of ≥10.11% and ≥4.13% observed under natural and artificial conditions, respectively. HSB-2 showed even higher CO_2 level and greater decrease in O_2 level compared to HSB-1 (Table 4). Throughout the storage period and under both conditions, PPW and JB maintained atmospheric levels of CO_2 (0.04%) and O_2 (20.90%). Yewle et al (2022) observed 7% oxygen in un-infested and 6% in infested hermetic bags after 6 months. In current study, oxygen levels were 14.47% naturally and 10.39% artificially, aligning with their trend. The significant CO_2 increase due to aerobic metabolism. Hermetic storage effectively manages oxygen compared to conventional, which maintains atmospheric levels.

The mean data on various observation showed that under natural condition, there was no F_1 adult emergence (number) of *R. dominica* in any of the three HSBs, while minimal F_1 adult emergence (0.44 to 0.72 adults) occurred under artificial condition. It was observed that under artificial condition, mean adult emergence (number) was statistically at par in HSB-2 and HSB-3, while differed significantly in HSB-1. JB exhibited the highest mean adult emergence (number), followed by PPW bag under both conditions. For grain damage, HSB-3 had the lowest mean grain damage (0.62 and 1.56%), which was at par with HSB-2 (0.64 and 1.65%) and differed significantly from HSB-1 (0.84 and 2.63%) under both natural and artificial conditions, respectively. Conversely, JB had the highest mean grain damage, followed by PPW bags under both the conditions. Similar trend was observed for mean grain weight loss (Table 5). When both the conditions were compared, highest mean grain damage and mean weight loss were observed under artificial condition. Mean seed germination of stored wheat was highest in HSB-3 (89.83 and 89.49%) under natural and artificial conditions, respectively, and was statistically at par with HSB-2 and HSB-1. JB exhibited the lowest germination rate, followed by PPW bags stored wheat under both conditions. Grain moisture was lowest in HSB-3 (11.34 and 11.36%) under natural and artificial conditions, respectively and was statistically at par with HSB-2 and HSB-1. Conversely, JB had the highest moisture content, followed by PPW bags under both conditions. CO_2 level was highest in HSB-3, followed by HSB-2 and HSB-1 under both conditions, with a more significant rise under artificial condition. Oxygen level declined with increased CO_2, with the lowest O_2 content observed in HSB-3 under both conditions. The decline in O_2 occurred under artificial condition compared to natural

Table 5. Comparison of mean effect of different bags on insect parameters

Treatments	Parameters					
	Adult emergence (number)		Grain damage (%)		Weight loss (%)	
	Natural condition	Artificial condition	Natural condition	Artificial condition	Natural condition	Artificial condition
HSG-1	0.00^c	0.72^c	0.84^c	2.63^c	0.23^c	0.79^c
HSG-2	0.00^c	0.55^d	0.64^d	1.65^d	0.15^d	0.52^d
HSG-3	0.00^c	0.44^d	0.62^d	1.56^d	0.13^d	0.45^d
PPW	4.54^b	7.25^b	9.75^b	16.86^b	5.71^b	11.07^b
JB	6.58^a	11.08^a	13.91^a	22.64^a	9.72^a	16.11^a

Mean values in the column followed with different superscripts significantly differ (p<0.05) using Tukey's test

Table 6. Comparison of mean effect of different bags on quality parameters and gaseous concentrations

Treatments	Parameters							
	Germination (%)		Moisture (%)		CO_2 (%)		O_2 (%)	
	Natural condition	Artificial condition	Natural condition	Artificial condition	Natural condition	Artificial condition	Natural condition	Artificial condition
HSG-1	89.41^a	88.91^a	11.44^c	11.47^c	6.69^b	9.63^c	18.21^b	12.06^b
HSG-2	89.58^a	89.20^a	11.38^c	11.40^c	6.71^b	10.51^b	14.85^c	11.61^c
HSG-3	89.83^a	89.49^a	11.34^c	11.36^c	8.84^a	11.27^a	14.47^d	10.39^d
PPW	79.08^b	71.37^b	12.94^b	12.98^b	0.04^c	0.04^d	20.90^a	20.90^a
JB	75.12^c	68.20^c	14.49^a	14.56^a	0.04^c	0.04^d	20.90^a	20.90^a

Mean values in the column followed with different superscripts significantly differ (p<0.05) using Tukey's test condition. PPW and JB maintained atmospheric CO_2 and O_2 levels throughout the storage studies (Table 6).

CONCLUSION

The comprehensive analysis revealed that hermetic storage bags, particularly HSB-3 demonstrated superior performance across various parameters and effectively mitigated adult emergence, minimized grain damage, preserved seed germination and moisture content compared to conventional PPW and JBs under both natural and artificial storage conditions. Moreover, HSBs exhibited controlled CO_2 and O_2 levels, with HSB-3 showed the highest CO_2 concentration and lowest O_2 content, indicative of effective insect suppression. These findings underscored the efficacy of hermetic bag storage technology in preserving grain quality and preventing insect-pest infestation, highlighting its potential for enhancing food security and reducing post-harvest losses in agricultural storage systems.

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Forecasting Model for Brown Wheat Mite, *Petrobia latens* (Muller) on Rainfed Wheat and Distribution in North-West India

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***Abstract*:** Brown wheat mite *Petrobia latens* (Muller) (Family Tetranychidae), is a serious pest of rainfed wheat in India. Its infestation is confined to relatively dry regions. It remains active during winter season with peak activity in March. In current study, mite population was recorded in wheat fields from 2004 to 2022 at Ludhiana, India. The population was recorded at 7 days interval, from 30 days after sowing till crop harvest and, correlated with meteorological data through multi-linear models fitted using the REG procedure in SAS model. In addition, periodic surveillance was also carried out in rainfed areas of Punjab-Himachal Pradesh border areas and field areas of Rajasthan. The results revealed that, in general, mite population starts increasing from January-February onwards, reached highest in March and, declined thereafter near crop harvest in April. The mite population showed a positive correlation with maximum and minimum temperature, relative humidity and sunshine, and a negative correlation with rainfall. A distribution map of *P. latens* was prepared. The incidence of brown wheat mite was observed on other crops also, including spices, weeds and pulses. The natural enemies belonging to family Anystidae, Phytoseiidae grubs and adults of Coccinellidae were also recorded.

***Keywords*:** Wheat, Brown wheat mite, Abiotic factors, Distribution

Wheat is the most widely cultivated cereal in the world with acreage of 225million hectares (MHa) during 2020-21 with global production of 792 million tonnes (MT) (USDA 2021). India is the second largest producer of wheat in the world and its cultivation has traditionally been dominated by the north and north western regions of the country India, wheat occupied 31.8 MHa during 2020-21 with production of 108.7 MT and average productivity was 3424 kg/ha . In Punjab state of India, wheat occupied 3.0 MHa with total production of 17.1 MT in 2020-21 (www.agricoop.nic.in2021)

Insect and mite pests infest wheat crop (Farook et al 2019) and significant yield losses have also been reported in many countries (Zhang et al 2022). In North-western plains of India, 5-10 percent losses in wheat yield due to biotic and abiotic factors are quite common Brown wheat mite (BWM), *Petrobia latens* (Muller), belonging to family Tetranychidae, is a serious pest of rainfed wheat and confined to relatively dry regions of the country, mainly north, north-west, central India. Although it is a pest of drier areas and is serious under rainfed condition but its incidence in the irrigated crops has also been reported (Sharma and Srinivasa 2004). The importance of this pest lies in its ability to infest large number of cultivated crops like wheat, barley, rapeseed, mustard, coriander, cumin, oats, maize etc, and also to survive in the egg stage during the hot summer months when wheat crop is not available. It remains active during winter with peak activity in March (Sharma and Srinivasa 2004, Bhullar et al 2014). The weather or abiotic parameters play an important role in the build up of pest populations in the cropping systems, which, in turn, can affect the overall productivity and require timely interventions for control of the pest populations (Mukhtar et al 2023, Bhullar et al 2014). Forecasting system for the pests in agro-ecosystem has become a major component in integrated pest management programmes. Considering this, pest weather relationship was established and prediction model was developed for implementing it in rainfed wheat system on regional basis in north Indian states. Based on the mite incidence and meterological data collected at Punjab Agricultural University, Ludhiana, from 2004 to 2013, pest incidence data was correlated with abiotic factors through multiple regression equation and a population prediction model was prepared during 2014-15 (Bhullar et al 2014). In continuity of these studies, the model was revalidated taking into account the data recorded thereafter in the recent years and more detailed observations on the bionomics of the pest. In the present studies, the revalidated population prediction model using SAS for the last 16 years, from 2004 to 2022, has been presented.

MATERIAL AND METHODS

The studies were carried out under the All India Network Project on Agricultural Acarology in collaboration with All India Coordinated Wheat and Barley Improvement programme during *rabi* (winter) seasons of 16 years viz. 2004 to 2022 at Punjab Agricultural University, Ludhiana (30°90′.88″ latitude and 75°.78′.81″ longitude and 247 m above sea level). Rainfed wheat variety PBW-175 and PBW-660 were grown as per recommended agronomical practices of the University. The plot size was kept as 8 square meter with three replications. The sowing time for rainfed wheat in north-west India is End October - Early November while harvesting is done from 1- 15 April.

Observations: The observation plots were maintained as sick plots over the years, without any irrigation imitating the rainfed like situations. The mite population was recorded at 7 days interval, from 30 days after sowing (DAS) till harvesting of the crop, from five marked spots/plot, between 12.00hrs and 14.00hrs. A simple technique to assess the population of *P. latens* on wheat plants was followed. The mite population was recorded randomly from five marked spots i.e. from four corners and one from the center of the plot between 12.00 hrs to 14.00 hrs. The sampling was done by gently tapping the plants to dislodge the mites over four glycerin smeared slides (2.5 x 7.5 cm) held in a thermocole sampler. The sampler consisted of rectangular (15 x 25 cm) thermocole slab of even thickness, on which four cavities were scooped to hold the slides. The thermocole sampler, with glycerin smeared slides was placed gently on the ground near the plant base. The plant adjacent to the sampler, was then struck, towards the slides, with a uniform force by hand six times. The mites falling on the slides were removed and kept in a slide tray. Counting of mites was done in laboratory under stereoscopic binocular microscope. The data, thus, collected were computed to the number of mites/10cm^2 slide area (The observations on mite population were recorded weekly after one month of sowing and continued till the harvesting of the crop.

Statistical analysis: The mite incidence was correlated with meteorological data i.e. maximum and minimum temperature, maximum and minimum relative humidity (RH), rainfall(RF), sunshine (SS), through multi-linear models fitted using the REG procedure in SAS model.

RESULTS AND DISCUSSION

Population prediction model: For development of population prediction model for brown wheat mite, *P. latens*, the correlation coefficient between the population of mites per month (number of mites/10cm^2 area) and the climatic factors i.e. maximum and minimum temperature, maximum and minimum relative humidity, rainfall and sunshine was worked out for the period from 2004-2022 and multiple regression equations worked out. The maximum and minimum temperatures during the last 16 years showed a decreasing trend in severe winter months i.e. December-January and start increasing from February onwards, whereas relative humidity is maximum in these months (Fig. 1). The winter rains are not very regular feature with intensity varying from negligible to moderate, and sunshine hours also vary greatly.

The general trend for seasonal incidence of *P. latens* pooled for 2004 to 2022 revealed that mite population starts increasing from January-February onwards reaching a maximum in March and declined thereafter near harvest of crop in April (Fig. 2). The mite population showed a positive correlation with maximum and minimum temperature and sunshine, whereas it showed a negative correlation with

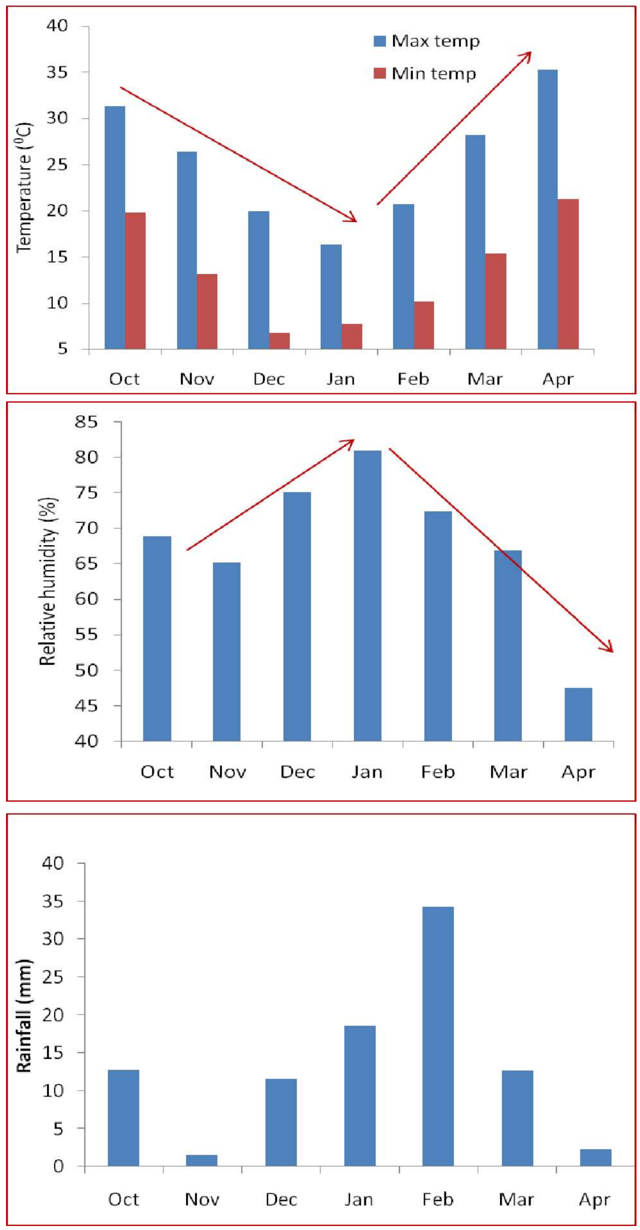
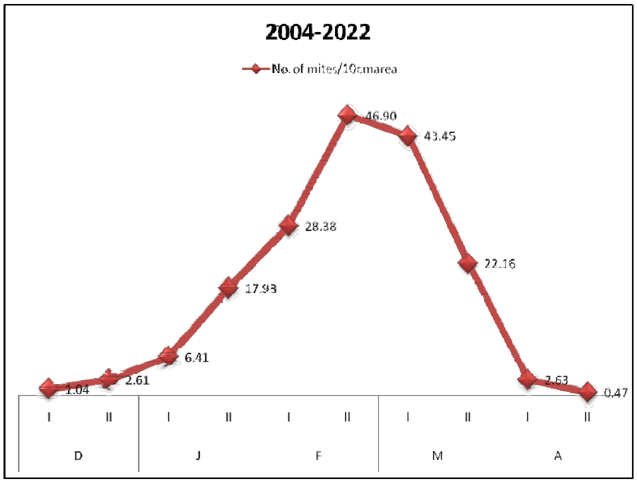


Fig. 1. Mean monthly meteorological data during wheat growing season at Ludhiana (India) from 2004-2022



D-December; J-January; F-February; M-march; A-April

Fig. 2. Pooled seasonal incidence of Brown wheat mite from 2004-2022

rainfall and relative humidity. During the years 2006-07 and 2010-12, when there was moderate to heavy rainfall the population of mites was less while in the years, 2004-05, 2008-09, 2009-11, when there was comparatively very less rainfall and increase in temperature during February-March, the population of mites was more. The coefficient of determination was calculated to measure the contribution of linear function of independent variables i.e. abiotic factors on dependent variables i.e. mite counts. The multiple regression equation was calculated to be, $Y = 94.0941 - 8.207X_1 + 3.617X_2 - 0.355X_3 - 0.553X_4 - 0.300X_5 + 21.277X_6$ ($R^2 = 0.2536$). It was observed that as the number of factors varies from 3, 4, 5 and 6, there is half-percent increase in predictions and the environmental factors explained 22- 24% variation in brown wheat mite population. So, whenever there is winter drought i.e. there is very less rainfall during December – February, the population of *P. latens* is expected to increase along with the increase in the minimum temperature (Bhullar et al 2014).

Later on taking into account the meterological data and mite incidence for the period 2014 to 2022, the model was revised and results interpreted for the period of 16 years viz. 2004 to 2022. The mite population showed a positive correlation with maximum and minimum temperature, relative humidity and sunshine, showed a negative correlation with rainfall (Table 1). The coefficient of determination (R^2) was calculated to measure the contribution of linear function of independent variables i.e. maximum temperature (X_1), minimum temperature (X_2), maximum relative humidity (X_3), minimum relative humidity (X_4), rainfall (X_5) and sunshine (X_6) on dependent variables i.e. mite counts. The multiple regression equation was also calculated:

$Y = -79.1755+1.5203(X_1).9333(X_2)+0.0493(X_3)+0.8341(X_4)+0.01628(X_5)+3.5256(X_6)$

R^2 (Coeff. of determination) = 0.0609

The individual weather parameters were plotted in SAS and correlations and regressions worked out. Brown wheat mite showed a positive correlation with maximum temperature, relative humidity and sunshine, whereas it showed a negative correlation with minimum temperature (Fig. 3). Based on all these, Multi-linear models were fitted using REG procedure in SAS model and following equations were calculated, wherein Y is the population of mites and dependent variable:

Case I: $Y = 5.1316 - 0.5019(T_{max})+0.506(RH_{max})+2.7985(SS)$ (R^2=0.0299)

Case II: $Y = 3.9288 - 0.5128(T_{max})+0.0518(RH_{max})+1.0176(RF)+2.8913(SS)$ (R2=0.0315)

Case III: $Y = 8.7953 - 1.2313(T_{max})+0.8941(T_{min})+0.0541(RH_{max}) + 0.7626(RF)+3.2890(SS)$ (R^2=0.0344)

Case IV: $Y = -79.1755+1.5203(T_{max})-0.9332 (Tmin) + 0.00493 (RHmax) + 0.8341 (RHmin) + 0.0162 (RF) + 3.5256(SS)$ (R^2=0.0609)

Based on this, it can be concluded that whenever there is winter drought i.e. there is very less rainfall and increase in the minimum temperature during December-February, the population of *P. latens* is expected to increase. It was observed that as the number of factors varies from 3, 4, 5 and 6, there is half-percent increase in predictions and the environmental factors explained 2-6% variation in brown wheat mite population under Punjab conditions. In winter drought i.e. there is very less rainfall during December – February, the population of *P. latens* is expected to increase along with the increase in the minimum temperature. Weather conditions, such as, heavy rainfall, can destroy most of the brown wheat mite populations and both dry and most conditions are needed by this mite to complete development. Singh and Jasrotia (2020) also observed that the incidence of brown wheat mite increased during February – March with peak intensity in March when the crop is around 120 days old.

A computer program based on Factor Analysis which could be used to analyze overall impact of weather parameters on aphid population dynamics was developed and integrated into APHID Sim simulation model successfully by Piyaratne et al (2014). Simulated results of the program showed that the catastrophe movements (sudden jumps) happening in growth of wheat aphid populations could be explained by considering overall weather effect as the weather factor for population analysis models. It cannot be explained clearly using only the single weather variable as a factor. Thus it was suggested that overall weather effect was

Table 2. Mean incidence of brown wheat mite, *Petrobia latens,* in different areas of north-west India in

Locality	GPS location	Mean number of mites/10cm^2 area		
		Crops	Spices	Weeds
Punjab-H.P. border areas				
District Hoshiarpur				
Bassi Mustafa	31.51161° N and 75.991792° E.	Wheat-2.50		*Cannabis*-1.50, Anystids-5
Patirian link road		Wheat-0.0		
Kharkan	31.501094° N and 76.051958° E.	Wheat-3.45		
Mehlanwali	31.495814° N and 76.016654° E.	Wheat-2.50		Grasses-3.50
				Sarkara grass-7.50
				Ageratum conyzoides (Billi goat weed)-20-25
Jatpur, Chabewal, Garhshankar		Wheat-0.0		
District Ludhiana				
Sick plots of PAU campus, Ludhiana	30.908769°, 75.788117°	Wheat-45.75		
		Chickpea- 0.0		
Rajasthan				
District Churu				
Churu	28.366168° N and 75.092442°' E.	Wheat-6.50		'*Pohli*'- 10.25
		Barley-3.00		
		Mustard –1. 15		
District Sikar				
Sikar RJ, Sabalpura rural	27.651485°N and 75.093591°E	Wheat-4.00		
Bhadala ki Dhani,RJ	27.472802°N and 75.380531°E	Wheat -0		
District Jaipur				
RARI,Durgapura	N26.843136°-E75.7836°	Wheat -50-60		*Solanum nigrum-1.25*
		Gram -0		Congress grass-0
		Linseed-2.0		*Rumex*-1.0
Dudu-Malpura road, farmer's field	N26.638877°-E75.266496°	Wheat-2.50		
		Gram -0		*Sisymbrium irio*-0.25
District Tonk				
V. Pachewar Karva	N26.48132°- E75.320893	Wheat-4.55		*Solanum nigrum*-0; *Aegeratum conyzoides*-0
RRS, Diggi	N26°21´29"-E75°27´48"	Wheat-0.75		
		Mustard- 0		
		Chickpea - 0		
V. Kekri	N26°51´17"-E75°11´21"	Wheat -0		
Kekri byepass	N25°57´29"-E75°9´4"	Wheat -0		
Kota				
Agriculture University Kota and KVK, Kota	N25°10´53"-E75°52´55"	Wheat 4.75 Anystid mite-1 per beating	Coriander -1.0 Coccinellids in abundance	Parthenium-3.50 Anystids-5.0
		Wheat Raj.4037-14.25; Wheat Raj 4079-2.56; Wheat Raj 1482-3.57; Wheat HI-8759-0 ; wheat PBW 343-1.15; wheat PBW 502-0 ; Wheat C-306-10.0		

Cont...

Table 2. Mean incidence of brown wheat mite, *Petrobia latens,* in different areas of north-west India in

Locality	GPS location	Mean number of mites/10cm^2 area		
		Crops	Spices	Weeds
		Wheat Raj.4037-14.25; Wheat Raj 4079-2.56; Wheat Raj 1482-3.57; Wheat HI-8759-0 ; wheat PBW 343-1.15; wheat PBW 502-0 ; Wheat C-306-10.0		
		Kota desi chana-1.0	Alsi - 0	*Lolium multiflorum* - 0
		Kota 'masar'-0.00	*Lepidium sativum*-0 'chandrashul'	
		Black gram-2.25	*Nizella saviva*-0 ' kalonji'	
		Kabuli chana - 0	Garlic - 0	
		Chia (*Salvia hispanica*)-0	Fenugreek - 0	
		Quinoa (*Chenopodium quinoa*) -0	'Kalonji' (*Nileja sativa*)-0	
		Mustard - 0		
		Curry patta-0.25		
Deoli		Wheat-2.25		Grasses-2.50
Kuchalwara Kalan	25.741194°,75.377939°	Chickpea-0.0		Wild grass, *Polypogon*-2.00
				Parthenium-6.50
		Wheat-2.50		*Xanthocarpium*-10-50
Kekri rural	25.936553°,75.163875°			Grasses-1.50; Anystids-2.0
Ajmer				
NRCSS, Ajmer	N26°27´7.56"-E 74°38´19.21"	Wheat-3.50	Fennel, 'saunf'- 1.15	*Xanthocarpium*-1.50
		Barley-2.25	Coriander-1.50	
		Jojoba - 0	Cumin 'Jeera'-1.0	Grasses- *Cymbopogan, Citronella* - 0
			Dill -0	
			Ajwain - 0	
			Kasuri Methi -0	
			Celery-2.0	
			Nigella-0	
			Anise-0.0	
			'Kalonji' - 0	
			Ajmer ajwain-1.0	
Doomara	26.368109°,74.592874°		Isabgol-bitter cumin-0.0 Aphids & thrips	
		Taramira-1.25		
Sathani	N 26.599704° E 74.316469°	Taramira-0.0		
District Nagaur				
Farmer's field	26.888551°.74.001187°	Isabgol-1.15	Fennel-1.00	
District Bikaner	N28°1´12"- E 73°19´3"			
SKNRAU, Bikaner		Wheat - 0		

Cont...

Table 2. Mean incidence of brown wheat mite, *Petrobia latens,* in different areas of north-west India in

Locality	GPS location	Mean number of mites/10cm^2 area		
		Crops	Spices	Weeds
		Mustard-1.0 Coccinellids in abundance	Onion - 0	
		Chickpea - 0	Garlic-0	
		Wheat - 0		
		Carrot - 0		
Lunkarnsar, Hariasar	N28°31´20"-E73°45´40"	Wheat-5.85		
Near KVK, Bikaner university		Mustard-0.0		
District Hanumangarh	N29°34´48"- E 74°19´12"	Wheat-7.85		

Table 1. Correlation co-efficient, regression between abiotic parameters and mean number of brown wheat mite on rainfed wheat (2004-2022)

Weather factors	Correlation coefficient (r)	Regression equation value	R^2
Maximum temperature(°C)	0.04873	Y=0.213X+12.07	0.0024
Minimum temperature (°C)	-0.04291	Y=0.254X+14.48	0.0018
Maximum relative humidity (%)	0.05814	Y=0.031X+14.38	0.0034
Minimum relative humidity (%)	0.01779	Y=0.035X+15.60	0.0003
Rainfall (mm)	0.01425	Y=0.360X+17.04	0.0006
Sunshine (hrs)	0.12826	Y=1.527X+6.481	0.0165

more suitable for catastrophe theory applications in population dynamics analysis as the weather factor. Similarly in the present studies, single weather parameter cannot possibly explain the change in the mite incidence and multiple weather factors might play a role in affecting the brown wheat mite population. Multi locational and extensive data in true rain-fed areas of Northern and Central India may be required for better explanation of relationship of mite population with environmental factors.

Surveillance and distribution mapping: During surveillance in different rainfed areas of Punjab, Punjab-Himachal Pradesh border areas, Rajasthan (Table 2), incidence of brown wheat mite was also observed on crops like mustard, radish, black gram, Bengal gram, lentils, *Eruca sativa*, fodder oat (*Avena sativa),* spices like coriander, carom seed, fennel, cumin but their intensity was low to moderate (4.65 to 37.65 mites/10cm^2 area), and weeds like *Aegeratum cinyzoidis, Phalaris minor Avena ludoviciana*, *Phalaris minor*, *Amaranthus viridis*, *Chenopodium album*, *Rumex maritimus*, *Convolvulus arvensis*, *Sisymbrium irio* , *Malva* sp., *Medicago denticulata* , and lemon grass, found growing inside and near the wheat fields. The mite incidence of mite was more during February-march in various localities..

Punjab : Almost all stages of brown wheat mite could be seen on soil clods, twigs of different crops, viz. pearl millet, maize, barley, wheat, weeds in the infested fields (Fig. 4). In Ropar, Hoshiarpur, and Ludhiana districts moderate to high infestation was observed on wheat and adjoining crops and weeds during second fortnight of March. In Anandpur Sahib , Hoshiarpur and Kiratpur areas, 35-137 mites/10cm^2 area were observed on wheat crop nearing maturity grown under rainfed conditions. Low intensity of mites (36.75 mites/10cm^2 area) was observed from second week of February to first week of March (99.38 mites/10cm^2 area) at Ludhiana campus of the University during different years when winter drought was there. Maximum mite population was observed during second week of March (824.47 mites/10cm^2 area) at the PAU Zonal Research Station, Kandi area, Ballowal Saunkhri (Dist. Hoshiarpur) in 2005. In recent years, however, the incidence of brown wheat mite has shown a declining trend as the area under rainfed wheat in Punjab has decreased drastically due to introduction of large number of submersible pumps in the area.

Himachal Pradesh: Mite incidence was found abundantly (15.35 to 46.50 mites/10cm^2 area) on local rainfed varieties in Kohari, Saidopul and Kandaghat in Solan district. Large number of mites was found on rainfed wheat even at a higher altitude of 1850 m in Village Barog of Solan district in 2004. In later years, mite infestation was observed in rainfed wheat, barley, weeds only along the Punjab-Himachal Pradesh border areas only as no infestation was observed in higher altitudes.

Rajasthan: In Rajasthan, districts of Jaipur (Durgapura, Mehlan, Dudu, Ramnagar and Dantri), Ajmer (Pulnea and Gagal) and Tonk (Dudu, Malpura Diggi, Beepur, Fagi, Gopalnagar and Renwala), Churu, Sikar, Kota, Deoli, Bhilwara, National Research Centre on Seed Spices, Ajmer; Bikaner, Hanumangarh, Pratapgarh, Chittorgarh, Udaipur and adjoining areas were surveyed periodically. In the year 2000, the fields were f heavily infested by mites. Tillers and in severe cases the earheads were also found infested. The

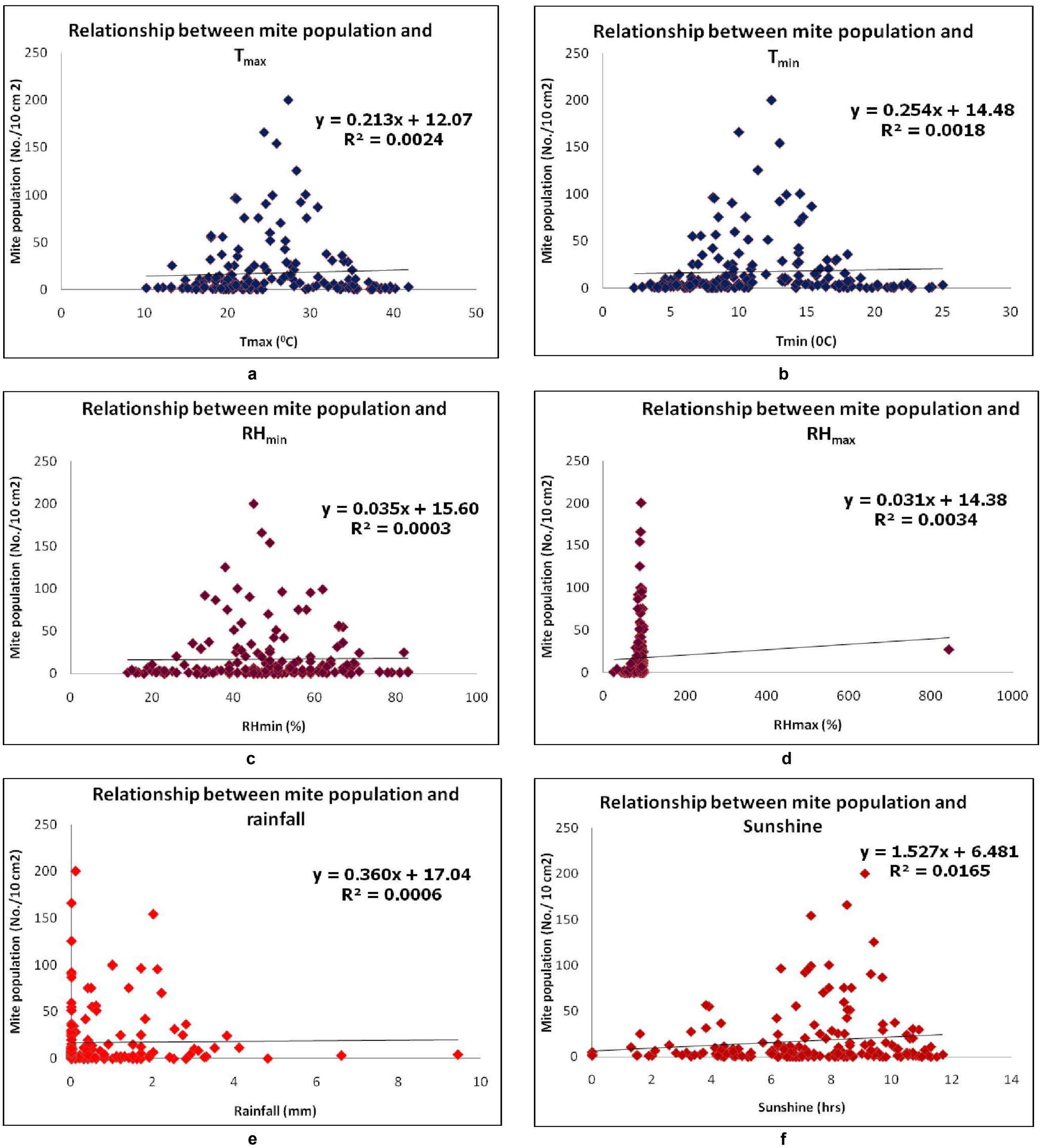


Fig. 3(a-f). Relationships between weather parameters and population of brown wheat mite, *Petrobia latens* infested plants turned yellowish. Heavily infested rainfed varieties were C-306 and Lok – 1 with 10-30% leaf damage in many areas. At RAU Research Station, Durgapura, Jaipur even the irrigated varieties were found heavily infested. The severely infested varieties were PBW-502, HP-1731, CBW-13, HD-2824, Raj – 4033, Raj – 4029, Raj – 3765 and Raj – 3077. On variety Raj-3765, severe mite infestation was seen on earheads (87.95 mites/10cm^2 area) also and even the flag leaves were damaged. Heavy infestation of mite was seen on adjoining weeds. By March end, the mite shifted to other non-host crops and survived there till the next wheat crop. Large number of eggs were found in the soil, where they remained in diapause state till the favourable conditions prevailed for further infestation on wheat (Bhullar et al 2022).

Fig. 4. Diapausing and non-diapausing eggs on stalks of pearl millet and soil

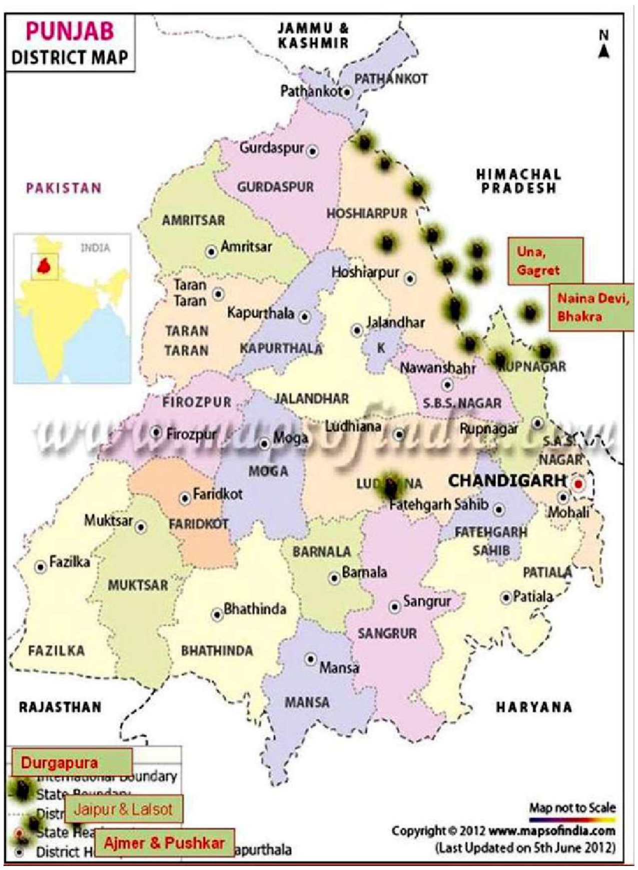


Fig. 5. Distribution map of Brown wheat mite in Punjab

In the studies in later years, especially the last 7-8 years, incidence of brown wheat mite has shown a varying pattern. Although the majority of the area in Rajasthan is rainfed, but still wheat crop is given 3-4 irrigations in many areas mostly by sprinkler system or drip irrigation, and the incidence of brown wheat mite has also been changing in the last few years. Low to moderate incidence (1.25 to 60.75 mites/10cm^2 area) of *Petrobia latens*, on wheat was observed in different areas of Rajasthan in the third week of February which increased to 85.25 – 92.65 mites/10cm^2 area in the first week of March. In addition, low incidence (1.0 to 3.25 mites/10cm^2 area) of BWM was also observed on barley; Linseed; Kota *desi chana*; Kota *Masur* ; *Eruca sativa*, *Avena sativa* and spice crops like coriander in Ajmer, fennel in Nagaur, cumin in Ajmer. Weeds like *Polypogon* grass, wild grass, Parthenium, *Xanthocarpium*; *Aegeratum cinyzoidis, Phalaris minor, Avena ludoviciana*, *Convolvulus arvensis* and *Sisymbrium irio* found growing inside and near the wheat fields.

Natural enemies: During survey, predatory mites belonging

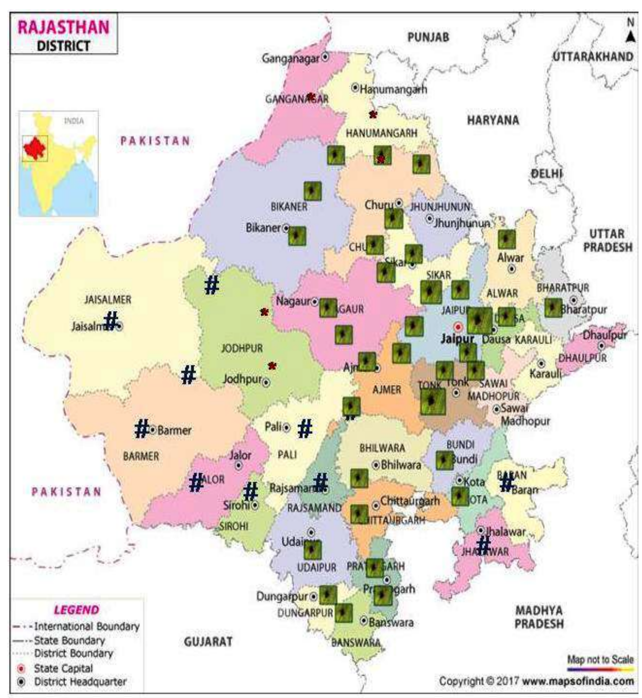


Fig. 6. Distribution map of brown wheat mite in Rajasthan

to family Anystidae (*Anystus baccarum, Tencatia villosa*) and Phytoseiidae (*Neoseiulius imbricatus*) were observed in almost all the localities of north-west India associated with the brown wheat mite. In addition, grubs and adults of coccinellid, *Cocinella septumpunctata* were found abundantly in association with wheat mite on wheat and adjoining weeds in March.

Distribution map: A distribution map of *P. latens*, based on surveys of different rainfed areas of Punjab – H.P. border areas, Rajasthan has been prepared (Fig. 5 and 6).

CONCLUSIONS

Studies carried out during *rabi* (winter) seasons of 16 years viz. 2004 to 2022 at Punjab Agricultural University, Ludhiana (30°90′.88″ latitude and 75°.78′.81″ longitude and 247 m above sea level). Brown wheat mite showed a positive correlation with maximum temperature, relative humidity and sunshine, whereas it showed a negative correlation with minimum temperature. Environmental factors explained 2-6% variation in brown wheat mite population under Punjab conditions

AUTHORS CONTRIBUTION

MBB – conceptualized the research topic, recorded data and conducted surveys in Punjab, H.P. and Rajasthan; BS – raising and maintenance of crop; PK – recorded data, conducted survey in Punjab; PKB – data analysis; JT – conducted field surveys in Rajasthan

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Transmission of Less Stinging Trait in *Apis mellifera* Linnaeus Colonies through Selective Breeding

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***Abstract*:** Studies on selective breeding for development of less stinging *Apis mellifera* colonies were carried out at Campus Apiary, Department of Entomology, Punjab Agricultural University, and at isolated mating yard at PAU Seed Farm, Ladhowal during 2021-2022. Ten least stinging colonies were selected as parent colonies from the stock of 100 colonies screened for defensive behaviour. Five daughter queens were reared from each mother queen colony. The drones were multiplied from only two of the 10 selected least stinging colonies. Selective mating between the newly reared gynes and drones was carried out at the isolated mating yard. The defensive behaviour of the colonies was assessed by alarm pheromone assay. The comparative assessment of the defensive behaviour between selected mother colony, F_1 colonies and control (unselected colonies) revealed that both mother and F_1 colonies had lesser number of stings/min, took more time to first sting and had lesser number of bees recruited for defense thus depicting defensive behaviour to be heritable. Among the 50 F_1 colonies, 62 per cent colonies showed improvement in this trait compared to just 10 per cent in the original stock (100 colonies). Correlation among the three defensive traits revealed that the number of stings/min was positively correlated with the number of bees recruited for defense and inversely with the time taken for first sting.

***Keywords*:** Alarm pheromone assay, *Apis mellifera*, Defensive behaviour, Isolated mating, Selective breeding

Honey bees are important from economic, nutritional, pharmaceutical, and commercial point of view as they provide various valuable hive products like honey, wax, royal jelly, bee venom, pollen, propolis, etc. Thus, contribute in the pollination of fruits, vegetables, and field crop plants, thereby increasing the crop productivity and improving the quality of produce. Punjab is one of the leading states in beekeeping, it contributes 14.1 per cent to the total honey production in India (Anonymous 2024). In beekeeping, honey bee behaviour such as honey production and hygienic behaviour are commonly used selection criterion for commercial breeding programmes. Honey bees defend their nests mostly around the entrance, although aggressive bees may follow intruders for considerable distances away from the colony. The two tasks of defensive behaviour include guarding the nest entrance and flying out of the nest, as well as stinging. The defense of a colony is the consequence of both guarding and responding behaviour exhibited by the worker bees (Breed et al 2004, Stabentheiner *et al* 2007). Aggression is a sequence of behaviours started by the colony's first line of defense, the guard bees, in response to a probable risk posed to the hive (Arechavaleta-Velasco and Hunt 2003, Breed et al 2004, Hunt 2007). Defensive behaviour of honey bees which has been described as a highly heritable trait, with genetic dominance and paternal effect can also be used for breeding less defensive honey bees(Breed et al 2004). Selective bee breeding is a tool for improving traits of apicultural interest that have an important impact on the beekeeping industry (Buchler et al 2013, Uzunov et al 2017). The benefits of selection are well recognized and can strongly affect the economic success of beekeeping. Honey bee colonies with less stinging behaviour would make the management of the colonies easier and would also promote beekeeping among the amateur beekeepers without the fear of being stung. Overall, in order to realize profits from beekeeping, a beekeeper needs the honey bee colonies with gentle temperament in terms of defensiveness. The benefits of selection for less defensive behaviour are well recognized and can positively impact the economic success of beekeeping. Thus, the present studies were conducted to develop less sting *Apis mellifera* colonies through selective breeding.

MATERIAL AND METHODS

The studies were carried out at Campus Apiary, Department of Entomology, Punjab Agricultural University, and at isolated mating yard at PAU Seed Farm, Ladhowal during 2021-2022. Ten least stinging colonies were selected as parent colonies from the stock of 100 colonies screened for defensive behaviour (Madaan et al 2024). Daughter queens were reared from each of the ten selected least stinging colonies by using PAU modified doolittle grafting method. The drones were multiplied from two of the 10 selected least stinging colonies. Selective mating between the newly reared gynes and drones was carried out at the isolated mating yard at PAU Seed Farm, Ladhowal. The defensive behaviour of the 10 parent *A. mellifera* colonies, 50 F1 daughter colonies and the control colonies was assessed by alarm pheromone (Madaan et al 2024). The observations recorded were time taken for the first sting in seconds (score of 1 for < 5 sec, 2 for 5.00-9.99 sec, 3 for 10.00-14.99 sec, 4 for 15.00-19.99 sec, 5 for 20 sec), number of stings received per minute (score of 5 for < 5 stings, 4 for 5.00-9.99 stings, 3 for 10.00-14.99 stings, 2 for 15.00-19.99 stings, 1 for 20 stings per min) and number of bees recruited for defense per minute (5 for < 10 bees, 4 for 10.00-19.99 bees, 3 for 20.00-29.99 bees, 2 for 30.00-39.99 bees, 1 for > 40 bees), the scores were given on a five-point scale of 1 to 5 wherein score of 1 represented the most aggressive and 5 represented the gentlest colony. Data were statistically analysed in completely randomized design . Pearson correlation analysis was used to test the significance of relationship among various parameters and p value was used to test the significance of correlation coefficients

RESULTS AND DISCUSSION

Relative number of stings: The least number of stings was 1.33 in M7D1 (Daughter colony No. 1 from M7) followed by 1.66 stings in M3D1 (Daughter colony No. 1 from M3) and M5D1 (Daughter colony No. 1 from M5) and revealed that the mother colonies maintained their position in score 5 as obtained in the screening experiment (Table 1). The performance of the F_1 daughter colonies was statistically on par with the mother colonies which had the score varied from 4-5 It was also observed that mother colonies and their daughter colonies had less number of stings as compared to the control colonies (10.80 stings), which showed that the trait is transmitted in daughter colonies.

Relative time taken to first sting: Variation among *A. mellifera* selected mother and their 50 F_1 daughter colonies in initiation of stinging response revealed the M10D4 (Daughter colony No. 4 from M10) took a maximum time of 23.00 s to initiate stinging response followed by 22.33 s in M2D1 (Daughter colony No. 1 from M2) and M2D2 (Daughter colony No. 2 from M2) (Table 1). The mother colonies registered a score of 4 with respect to time taken to first sting. Performance of the F_1 daughter queens' performance was better or on par as compared to the mother colonies, registering a score of either 4 or 5, respectively.

Relative number of bees recruited for defense: The least number of bees recruited for defense was 5.33 bees observed in M6D4 (Daughter colony No. 4 from M6) followed by 6.00 bees in M10D5 (Daughter colony No. 5 from M10). Mother colonies lie in the score of 4 while F_1 daughter colonies in the score of 4 or 5. Thus daughter colonies performed better than or on par to the mother colonies. The mother and F_1 daughter queen colonies recorded less number of bees recruited for defense when compared with control colonies (20.73 bees). On the basis of cumulative score, six F_1 daughter colonies lie in score 15, eight colonies in score 14, 27 in score 13, eight colonies in score 12 and eleven colonies in score 11 (Fig. 1).

Improvement in less stinging tendency in F_1 colonies: The selective breeding for less stinging honey bee colonies resulted in overall reduction in aggressiveness of colonies reared from the selected mother colonies as 62 per cent of the F_1 daughter colonies lie in the highest score category (13-15) as compared to only 10 per cent in the initial stock of colonies (Fig. 2). The highest cumulative score (all the three parameters) of 15 was achieved by 12 per cent F1 colonies compared to only one colony from original stock. In original stock 62 per cent of colonies were in high stinging range (score 4-10) whereas selective breeding resulted in not even a single colony falling in this score range. Correlation among the three defensive traits revealed that the number of stings/min was positively correlated with the number of bees recruited for defense and inversely with the time taken for first sting (Table 2) indicated that a colony that inflicts more number of stings on the leather ball will have more number of bees recruited for defense and these will take less time to initiate defense.

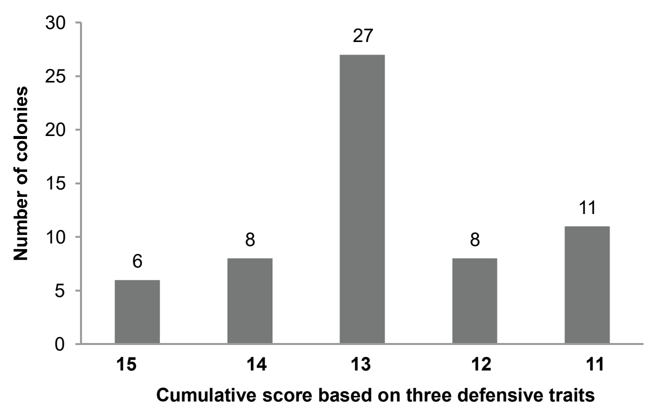

Fig. 1. Grouping of mother and F_1 colonies based on the cumulative score of three defensive traits

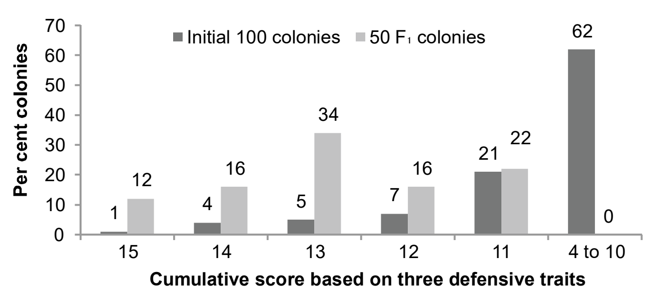

Fig. 2. Comparative cumulative score based on three defensive traits in F1 and initial stock of *A. mellifera* colonies

Table 1. Relative defensive behaviour of *A. mellifera* mother and F_1 colonies

Colony No.	Mean no. of stings per minute	Score	Time taken for first sting (s)	Score	No. of bees recruited for defense	Score
M2D1	2.00	5	22.33	5	9.67	5
M2D2	2.00	5	22.33	5	7.67	5
M3D5	2.33	5	20.33	5	9.67	5
M4D2	2.67	5	21.33	5	9.67	5
M8D5	2.00	5	21.00	5	8.00	5
M10D5	2.00	5	20.33	5	6.00	5
M3D1	1.67	5	17.67	4	6.67	5
M4D4	4.33	5	20.67	5	11.33	4
M6D4	2.33	5	16.00	4	5.33	5
M7D1	1.33	5	15.67	4	6.67	5
M8D2	2.67	5	21.67	5	11.33	4
M9D2	3.00	5	21.33	5	11.67	4
M10D4	3.33	5	23.00	5	14.00	4
M3D3	3.33	5	15.00	4	8.67	5
M1D2	4.00	5	13.00	3	7.33	5
M1D4	5.33	4	22.00	5	10.00	4
M4D5	3.33	5	14.00	3	9.33	5
M5D1	1.67	5	14.67	3	7.67	5
M5D4	2.67	5	18.67	4	11.00	4
M7	4.67	5	16.67	4	14.33	4
M7D5	2.67	5	13.33	3	9.33	5
M8D4	3.33	5	16.00	4	13.00	4
M1	4.33	5	15.66	4	12.33	4
M2	2.67	5	16.66	4	12.67	4
M3	4.67	5	19.00	4	15.00	4
M5	4.33	5	15.00	4	15.33	4
M8	4.67	5	15.33	4	15.67	4
M9	4.33	5	15.33	4	14.33	4
M6	4.33	5	17.66	4	15.33	4
M10	3.33	5	17.00	4	12.33	4
M4	4.66	5	19.33	4	13.00	4
M1D1	5.33	4	16.00	4	9.33	5
M1D5	3.67	5	15.66	4	15.66	4
M2D3	3.67	5	15.66	4	14.67	4
M2D4	2.33	5	18.00	4	12.33	4
M2D5	4.33	5	15.00	4	13.00	4
M6D1	2.66	5	17.66	4	12.67	4
M6D3	3.33	5	16.33	4	15.33	4
M6D5	4.33	5	18.00	4	14.67	4
M7D2	4.67	5	16.67	4	16.66	4
M9D1	3.67	5	16.00	4	11.67	4
M7D3	3.00	5	13.66	3	11.00	4
M8D1	4.33	5	13.00	3	14.33	4

Cont...

Table 1. Relative defensive behaviour of *A. mellifera* mother and F_1 colonies

Colony No.	Mean no. of stings per minute	Score	Time taken for first sting (s)	Score	No. of bees recruited for defense	Score
M8D3	4.00	5	13.33	3	14.67	4
M9D4	4.67	5	14.33	3	15.67	4
M9D5	3.33	5	13.00	3	14.00	4
M10D1	3.00	5	13.33	3	10.33	4
M6D2	5.00	4	15.33	4	15.33	4
M10D3	3.66	4	15.33	4	16.00	4
M1D3	5.67	4	14.33	3	10.00	4
M3D2	5.00	4	14.33	3	14.33	4
M3D4	5.33	4	14.00	3	15.00	4
M4D1	4.66	4	14.33	3	16.67	4
M4D3	5.33	4	14.00	3	15.00	4
M5D2	5.00	4	14.66	3	16.33	4
M5D3	7.67	4	14.66	3	16.00	4
M5D5	5.33	4	13.66	3	14.33	4
M7D4	6.33	4	13.66	3	15.66	4
M9D3	5.33	4	13.66	3	13.00	4
M10D2	5.00	4	14.00	3	12.67	4
Control	10.80	3	10.26	3	20.73	3

M1 to 10 Mother colony; D1 to D5 Daughter colony No. 1-5 from respective mother colony Scoring
Mean no. of stings/min: 5 for < 5 stings, 4 for 5.00-9.99 stings, 3 for 10.00-14.99 stings, 2 for 15.00-19.99 stings, 1 for 20 stings/min
Time to first sting (s): 1 for < 5 sec, 2 for 5.00-9.99 sec, 3 for 10.00-14.99 sec, 4 for 15.00-19.99 sec, 5 for 20 sec to first sting
No. of bees recruited: 5 for < 10 bees, 4 for 10.00-19.99 bees, 3 for 20.00-29.99 bees, 2 for 30.00-39.99

Table 2. Correlation coefficients among the number of stings, time taken to first sting and number of bees recruited for defense in F_1 colonies

Trait	No. of stings/min	Time taken (s)	Recruitment of bees (No.)
No. of stings/min	-	-0.402**	0.643**
Time taken to first sting (s)	-0.402**	-	-0.364**
Recruitment of bees (No.)	0.643**	--0.364**	-

n = 150; p (0.01): 0.211; ** r significant at 1 % level of significance

CONCLUSIONS

The successful transmission of less stinging trait in F1 and thereby significant reduction in stinging tendency of bees has been achieved. The information generated from the study on the less stinging behaviour will be helpful in further bee breeding work towards developing less stinging *A. mellifera* strain.

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Bio-Ecology of Lepidopteran Pests and Natural Enemies in Rice Ecosystem of Balaghat District

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Abstract: In India, tentatively 100 insects have been reported as pests of rice and 20 of these are accepted to be key pests causing more than 30% yield loss from germination to harvest of the crop. The stem borers and leaf folders both are of economic importance and they damage the rice plants at all the stages of crop growth and are the key factors responsible for poor rice yield. In view of the above background the present experiments were conducted to study on “Bio-ecology of stem borer and leaf folder in rice ecosystem of Balaghat district” to find out the seasonal incidence and species diversityof stem borer and leaf folder with natural enemies in rice ecosystem. The highest mean percent dead heart and white ear head caused by stem borer were recorded in Mehandiwada village of Waraseoni and lowest percent were recorded in Belgoan village of Lallburra. Whereas, the maximum percent damaged leaves caused by leaf folder was recorded in Bakoda village followed by Mohgaon village (5.17% DL) of Lalburra block and minimum percent damaged leaves (4.39%) was recorded in Savngi village of Waraseoni block followed by Sihora (4.50% DL) village of Lalburra block and Kope (4.55% DL) village of Waraseoni block. The total numbers of five natural enemies *i.e.* hymenoptera wasp, orthoptera grasshoppers (meadow grasshopper), odonata fly (dragonfly and damselfly), hemipteran bugs and spider were observed at different stages of crop growth. Among natural enemies, the abundance was in the order of meadow grasshopper > Odonata fly >hymenoptera wasp > spider > hemipteran bugs. The three species of stem borer *i.e. Scirpophaga insertulas*, *Sesamia inferens* and *Scirpophaga innotata* were observed in Balaghat district Among all three species of stem borer, the highest population was recorded with *Scirpophaga insertulas* (71.24%) and followed by *Sesamia inferens* (20.61%) and *Scirpophaga innotata* (8.16 %). The three species of rice leaf folder *i.e. Cnaphalocrosis medinalis, Marasmia patnalis* and *Marasmia ruralis* were observed in Balaghat district. Among all three species of leaf folder, the highest population (85.16%) was observed with *C. medinalis* followed by *M. patnalis* 12.38% and *M. ruralis* 2.46%.

Keywords: Species diversity, Seasonal activity, Stem borer, Leaf folder, Bioecology

Rice is one of the most important cereal crops which providing food for nearly half the population at the global level (Fukagawa and Ziska 2019). More than 2000 million people in Asia and 100 million in Africa and Latin America depend on rice as a major food. In India, rice grows up in about 43.86 million hectares with a production of 112.91 million tonnes that shares 19.51 percent of world rice production with average productivity of 2578 kg/ha (Anonymous, 2020). In India, insect pests are the most important biological constraints limiting rice yield potential and reflect large scale reduction both in quality and quantity throughout the world (Arora *et al*., 2019). More than 10 species of insect pests have been reported to severe damage on rice crop in Madhya Pradesh, of which stem borers (*Scirpophaga* sp., *Chilo* sp. and *Sesamia inferens* Walk.) and leaf folders (*Cnaphalocrocis medinalis*, Guen. and *Marasmia patnalis*, Bradley) are key factors responsible for poor rice yield. The stem borer feeds on the inner part of the stem without cutting it, which shows the dead heart during their growth stage, which results in a reduction in the spirelets per panicle, hindering the ripening of panicles, which eventually leads to grain weight loss (January et al 2020). The rice leaf folder affects the plant by causing transparent patches on the leaf as it feeds on the foliage and scraps the green mesophyll tissue of the plant (Chintalapati et al 2017).

MATERIAL AND METHODS

The experiments were conducted at Research Farm of JNKVV-College of Agriculture, Balaghat, Murjhad Farm, Waraseoni and farmer's field of Balaghat district, Madhya Pradesh during two consecutive *Kharif* seasons of 2019 and 2020. Two blocks from the Balaghat district *i.e.* Lalburra and Waraseoni were selected for the survey works of the study. The 1250 samples were observed from these two blocks in 5x5x5x5 manner (*i.e.* five villages from each block, five fields from each village and five spots from each field and five hills from each spot). Observations were recorded at fifteen days interval from nursery to harvest during *kharif* 2019 and 2020. Standard procedure was followed to record the observations on incidence of stem borers and leaf folders of paddy (Bentur et al 2012).

Stem borer: Counts were taken on a number of dead hearts/white ears and a total number of tillers/panicles from five randomly selected hills. The percent incidence (dead heart/ white ears) was calculated.

Leaf folder: The damaged leaves and a total number of leaves from 10 randomly selected hills were observed in each plot. The percentage of leaf damage was calculated.

Species diversity: The total 50 adults of the stem borers and 50 adults of the leaf folders were collected from different locations of two blocks in the Balaghat district. Stem borer and leaf folder moth's abundance was determined by collection from sweep net and light traps sampling from different locations. The observation on adults of stem borer and leaf folder was done by collection from insect net and light traps from selected places. The percentage of occurrence of stem borer and leaf folder in the collected population from different regions was also worked out.

Natural enemies: The population counts of the natural enemies were made simultaneously in all the same locations and on the same spot-on which insect pest population was recorded. Total 20 sweeps of collection net were made on five spots from each field. The observations were recorded at 30, 45, 60, 75 and 90 days after transplanting. The common predators such as wasps, spiders, mirids, dragon flies and grasshoppers were counted on each spot and averaged to express per 20 sweep basis.

RESULTS AND DISCUSSION

Seasonal Incidence

Stem borer: The average egg mass of 0.055 per hill was recorded in 10 villages of two blocks during *kharif,* 2019 and 2020. Among the villages, the maximum number of egg mass *i.e.* 0.101 per hill in Ganeshpur and minimum egg mass (0.022/hill) in Savngi. Highest mean (5.96%) dead heart was in the Mehandiwada and the lowest (3.52%) in Belgoan village. The maximum percent dead heart was recorded 45 days after transplanting with 7.78 % during the survey period at the farmer field. The highest percent (6.48%) of ear head was in Mehandiwada whereas, the lowest (2.38%) in Belgoan followed by Savngi (2.86%). The highest white ear head was at 90 days after transplanting (10.04%). Das (2020) reported seven insect species *viz., C. medinalis* (Guenee), *S. incertulas* (Walker), *M. separate* (walker), *Leptocorisa* spp, *Nilaparvata lugens* (Stal), *Nephotettix nigropictus* (Stal) and *N. virescence* (Distant) were recorded as major pests in paddy field. Among them, YSB (*S. incertulas*) were dominant pest species of rice cultivated in the study area. Bisen et al (2019) YSB were more in the mid to last of September, leaf folder increases at the time of reproductive phase in mid of September. Ghosh et al (2016) reported that the YSB (*S. incertulas*) were the major and serious pests of rice plant in Burdwan district, West Bengal. Justin and Preetha (2014) reported the maximum incidence of stem borer in Agasteeswaram, Thovalai and Thuckalay blocks in Kanyakumari District. Adhikari et al (2018) reported that the *S. incertulas* was observed throughout the crop season, while its highest abundance were at the tillering stage in Chitwan and the milking stage in Lamjung. Saini (2017) reported the highest population of *S. incertulas* was recorded in Thirur (76.79%), *S. fusciflua* recorded highest from Killikulam (5.88%) and *S. virginia*was recorded in Thirupathisaram (1.90%) and reported first time from Tamil Nadu in India.

Leaf folder: The maximum (5.46%) damaged leaves was recorded in Bakoda followed by Mohgaon and Newargaon village and minimum was in Savngi village (4.39%) followed by Sihora and Kope. The highest percent of damaged leaves was recorded 60 days after transplanting (9.06%), whereas, the lowest was at 90 days (2.02%) followed by 30 days after transplanting. Das (2020) observed that leaf folder (*C. medinalis*) was highly abundant and dominant pest species of rice cultivated in the study area. The present findings were supported by the findings of Ghosh et al (2016) in Burdwan district, West Bengal and they reported that leaf folder (*C. medinalis*) was the major and serious pests of rice plant.

Natural enemies: The five natural enemies *i.e.* hymenoptera wasp, meadow grasshopper, odonata fly (dragonfly and damselfly), hemipteran bugs and spider were observed at different stages of crop. The highest relative abundance of meadow grasshopper (29%) was recorded and lowest (15%) was in spider and hemipteran bugs. Among natural enemies, the abundance was in the order of meadow grasshopper > odonata fly >hymenoptera wasp > spider > hemipteran bugs. On the basis of the mean of all natural enemies, the highest activity was recorded at the late tillering stage *i.e.* 60 days after transplanting followed by the panicle initiation stage *i.e.* 75 days after transplanting. Kumar *et al.* (2013) and Rautaray (2019) reported that the common natural enemy fauna of rice leaf folder *C. medinalis* comprised of 10 species predatory arthropods. Rahaman et al (2014) reported nine different natural enemies were collected

Table 1. Seasonal incidence of stem borer and leaf folder (Pooled mean of *Kharif,* 2019 and 2020)

Block	Village	Egg mass/hill*	DH per cent (%)				WEH per cent (%)			Damaged leaves percent (%)			
			30 DAT	45 DAT	60 DAT	Mean	75 DAT	90 DAT	Mean	30 DAT	60 DAT	90 DAT	Mean
Lalburra	Ganeshpur	0.101	5.37	7.00	4.31	5.56	2.08	9.04	5.56	3.00	8.76	1.55	4.89
	Bakoda	0.062	4.25	6.59	4.67	5.17	2.37	7.56	4.97	2.42	10.08	1.49	5.46
	Belgaon	0.034	3.13	4.96	2.49	3.52	1.05	3.70	2.38	2.23	9.04	2.76	4.82
	Sihora	0.038	3.94	5.14	4.66	4.58	1.28	6.09	3.69	1.97	8.11	2.12	4.50
	Mohgaon	0.060	4.02	5.22	3.67	4.30	2.11	6.43	4.27	2.82	9.17	2.43	5.17
	Mean	0.059	4.14	5.78	3.96	4.63	1.78	6.56	4.17	2.49	9.03	2.07	4.97
Waraseoni	Kope	0.035	4.40	6.40	3.86	4.88	2.02	7.25	4.64	2.92	8.53	2.82	4.55
	Kayadi	0.037	4.12	5.74	3.43	4.43	2.23	5.90	4.07	2.09	10.36	1.34	4.82
	Mehndiwada	0.086	5.27	7.78	4.85	5.96	2.90	10.04	6.48	3.62	7.69	1.85	4.77
	Savngi	0.022	3.37	5.16	1.97	3.50	1.12	4.61	2.86	2.03	9.03	2.13	4.39
	Newargaon	0.078	4.56	7.03	4.66	5.42	2.44	9.02	5.73	2.32	9.78	1.69	5.15
	Mean	0.052	4.34	6.42	3.75	4.84	2.14	7.36	4.76	2.59	9.08	1.98	4.76
Overall mean		0.055	4.24	6.10	3.86	4.73	1.96	6.96	4.47	2.54	9.06	2.02	4.85

*Average of three observations (15 days after sowing, 50 & 70 days after transplanting (DAT); DH= dead heart, WEH= white ear head from the rice fields and recorded. The population of natural enemies was highest in tillering stage and lowest in seedling stage. The relative abundance of natural enemies as ladybird beetle >long jawed spider>wolf spider>damselfly>carabid beetle>green mirid bug>lynx spider>dragon fly>ear wig.

Species Diversity

Stem borer: The three species of stem borer *i.e. S. insertulas* (YSB), *S. inferens* (PSB) and *S. innotata* (WSB) were observed during *Kharif,* 2019 and 2020. Among all three species, the highest population was of YSB (71.24%) in all three species followed by PSB (20.61%) and WSB (8.16 %). Baskaran et al (2017) reported that three species of stem borer including *S. incertulas*, *C. suppressalis* and *S. innotata* but *S. incertulas* dominated. Rahaman et al (2014) reported five stem borer species viz; YSB, PSB, DSB, SSB (*Chilo suppressalis*), WSB (*Scirpophaga innotata*) from the rice fields. The population of stem borers highest in tillering stage and lowest in seedling stage. The relative abundance of stem borer species under investigation showed ranking order; yellow stem borer >dark headed stem borer>pink borer>white borer>stripped stem borer. Kumar (2012) reported the four species of stem borer of rice *viz.* YSB, PSB, WSB, and DSB were prevalent during the crop season. However, YSB was dominant over other species of stem borer. Kanagaraj *et al.* (2019) reported three species of rice stem borers *viz., S. incertulas, S. inferens, C. polychrysus* occurred among which the first was dominant. Sampathkumar and Ravi (2013) reported that three stem borers species *viz*., YSB, PSB and dark headed borer were found in all the regions except in the hilly Zone where YSB was the only species present.

Leaf folder: The three species of rice leaf folder *i.e.. C. medinalis, M. patnalis*and *M. ruralis* were observed in Balaghat district. Among all three, the highest population was observed with *C. medinalis* (85.16%) followed by *M. patnalis* and *M. ruralis* . Among different villages, *C. medinalis* numbers ranged from 80.30 to 89.37 % with an average percent of 85.16 % at different growth stages of rice crop in two blocks of Balaghat district. Kanagaraj et al (2019) reported three species of rice leaf folders *viz., C. medinalis, M. patnalis* and *M.ruralis* occurred among which the first was dominant. Rautaray (2019) revealed that three rice leaf folder species were noticed *i.e. C.medinalis* (Guenée), *M.exigua* (Bradley) and *Brachimea arotraea* (Meyrick) with the predominance of *C. medinalis*.

Table 2. Species diversity ratio of stem borer and leaf folder (Pooled mean of *Kharif,* 2019 and 2020)

Block	Village	Stem borer			Leaf folder		
		Scirpophaga incertulas (YSB %)	*Sesamia inferens* (PSB %)	*Scirpophaga innotata* (WSB %)	*Cnaphalocrosi medinalis*	*Marasmia patnalis*	*Marasmia ruralis*
Lalburra	Ganeshpur	70.66	21.56	7.78	86.44	10.64	2.93
	Bakoda	70.96	19.91	9.13	83.88	14.04	2.09
	Belgaon	69.89	21.36	8.76	89.37	9.15	1.49
	Sihora	72.92	19.27	7.82	80.30	15.27	4.43
	Mohgaon	74.32	21.46	4.22	86.56	12.72	0.73
	Mean	71.75	20.71	7.54	85.31	12.36	2.33
Waraseoni	Kope	69.01	20.17	10.82	85.18	11.58	3.25
	Kayadi	70.98	19.93	9.09	85.37	11.41	3.23
	Mehndiwada	69.88	19.05	11.08	86.66	12.00	1.35
	Savngi	72.86	21.67	5.47	81.70	14.20	4.11
	Newargaon	70.86	21.75	7.39	86.18	12.84	0.99
	Mean	70.72	20.51	8.77	85.02	12.40	2.58
Overall mean		71.24	20.61	8.16	85.16	12.38	2.46

YSB= yellow stem borer, PSB= pink stem borer, WSB= white stem borer

Table 3. Abundance of natural enemies in rice ecosystem of Balaghat district (Pooled mean of *Kharif,* 2019 and 2020)

Natural enemy	Population/20 complete sweeps				
	15 DAT	30 DAT	60 DAT	90 DAT	Mean
Hymenopterans wasps	3.61	7.00	14.55	6.72	8.93
Orthoptera grasshoppers	4.85	9.41	22.40	10.94	13.37
Odoneta flies	8.97	11.60	13.25	2.49	9.92
Hemipteran bugs	1.91	5.19	12.10	4.07	6.74
Spiders	0.00	0.00	10.17	11.67	6.82
Mean	3.87	6.64	13.91	7.18	9.16

DAT= date of transplanting

CONCLUSION

The highest infestation of stem borer was observed in Mehandiwada village of Waraseoni and lowest in Belgoan village of Lallburra. The maximum percent damaged leaves was recorded in Bakoda and minimum was in Savngi village. The five natural enemies (hymenoptera wasp, meadow grasshopper, dragonfly and damselfly, hemipteran bugs and spider) were observed at different stages of crop growth. The *S. insertulas* and *C. medinalis* were predominant species of stem borer and leaf folder respectively, in rice ecosystem of Balaghat district. The peak activities of stem borers and leaf folders were recorded at tillering stage in 4th week of August and at panicle stage during 3rd week of September, respectively. The maximum activities of natural enemies were at vegetative and panicle stage of rice crop.

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Influence of Constant Temperatures on Growth and Development of *Pectinophora gossypiella* (Saunders) in Bt cotton

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Abstract: The study on 'Influence of temperature on growth and development of *P. gossypiella* in Bt cotton' was studied at various constant temperatures of 15, 20, 25, 30, 35 and 40°C) in Integrated Pest Management Laboratory, Department of Entomology, PAU, Ludhiana during *kharif* 2022-23. The results revealed that duration of all the larval instars were significantly lower at constant temperature of 35°C. The pupal duration, adult longevity and total developmental period of male and female were recorded significantly lower at 35°C. The fecundity and egg, larval and pupal survival was recorded highest at 30°C whereas at 40°C, no egg hatching and all the larvae experienced mortality. The larval and pupal weights were recorded highest at constant temperature of 35°C. The correlation was worked out where the developmental parameters have shown significant negative correlation with constant temperatures. All the larval instars and male pupal weights show significant positive correlation with constant temperatures and female pupal weight, egg, larval and pupal survival show non-significant positive correlation with constant temperatures. Constant temperature dependant set with Stinner nonlinear and inverse second order polynomial model for the development of *P. gossypiella*.

Keywords: Adult longevity, Constant temperatures, Fecundity, *Pectinophora gossypiella,* Total developmental period, Survival

Cotton (*Gossypium* spp), often referred to as the 'King of Fibers,' is a highly valuable fiber crop cultivated in both tropical and warm temperate regions worldwide. China is the leading producer of cotton globally, with India as the second-largest producer, yielding an estimated 343.74 lakh bales during 2022-23 (Anonymous 2023). In Punjab, cotton ranks as the second most significant *kharif* crop after rice, covering approximately 3.25 lakh hectares in the 2021-2022 season which was an increase of about 75 thousand hectares from the previous cropping season, yielding 21.86 lakh quintals of cotton (Anonymous 2022). The introduction of Bt cotton hybrids to India in 2002 resulted in a significant reduction in bollworm infestations (Manjunath 2004). After a decade, since the introduction of Bt cotton, the pink bollworm (PBW), *Pectinophora gossypiella* (Saunders) (Lepidoptera: Gelechiidae), has emerged as a significant threat in the cotton-growing regions of Central and Southern India. There have been reports of the insect feeding and surviving on both single-gene Bt cotton (Bollgard I) and dual-gene Bt cotton (Bollgard II) in Gujarat (Dhurua et al 2011). This pest has become a major concern for cotton production in the Southern and Central regions of India, where it has developed resistance to Cry1Ac and Cry2Ab expressing cotton. Additionally, it has shown resistance to insecticides and has started infesting late-season cotton (Naik et al 2018). The survival of this insect is notably influenced by temperature and relative humidity under climatic conditions. Therefore, understanding how pink bollworm responds to variations in temperature and relative humidity is crucial. This knowledge is essential for modifying pest management strategies in response to climate change (Shrestha 2019). The status of this pest species can be significantly affected by changes in temperature. Therefore, studying the impact of temperature on insect development is vital for estimating seasonal and phenological development, understanding pest population dynamics, conducting risk analysis, forecasting pest outbreaks, and developing effective management strategies to minimize pest populations in the field.

MATERIAL AND METHODS

Raising of test plant: The pure seed of RCH 773 BG-II cotton cultivar was procured from the local market. Two to three seeds of this cultivar were sown at 10 days interval in earthen pots filled with soil and farmyard manure to get a continuous supply of required stages of bolls for conduct of various experiments.

Initiation and maintenance of culture of *P. gossypiella*: The larvae of the pink bollworm were collected from infested cotton fields in the cotton belt (Bathinda, Mansa, Abohar and Mutksar districts) of Punjab. The larvae were fed on flower/cotton bolls of non-Bt cotton cultivar, F 2228 in the laboratory at room temperature. To ensure their survival, food was provided on a daily basis. Male and female pupae were kept in plastic jar with 10×15 cm diameter. To facilitate the females to lay eggs in the oviposition cage, 10-15 days old boll was provided as substrate for the egg laying. The cage was covered with black muslin cloth at the top and side.

Experimental procedure: The mentioned set of minimum and maximum temperature treatments where T1- 15±1°C, T2- 20±1°C, T3- 25±1°C, T4- 30±1°C T5- 35±1°C and T6- 40±1°C along with five replications each was maintained for 14:10 hour in an incubator. The relative humidity was maintained 65±5 per cent throughout the experiment. Twenty neonate larvae were used in each treatment and three such replications were maintained in different plastic jars (10 cm diameter and 18 cm height) by using camel hair brush and the larvae was fed on the locules of Bt cotton cultivar, RCH 773. For recording the duration of each instar, cut the locules and examine it for casted skin. To record the fecundity, detached cotton bolls of 10-15 days old was wrapped with moist cotton wick and placed in eppendorf tubes filled with 10 per cent sucrose solution to keep the cotton bolls fresh and this was placed in the oviposition cage of 14.5 x 20.5cm diameter (Fand et al 2019). For mating purposes, five pairs of newly emerged adults were introduced into an oviposition cage (14.5x20.5 cm diameter). The eggs which were laid by the adult female moth were collected separately. The cotton shoots were replaced after every two days. The number of eggs deposited on the old twig was counted.

Data for temperature dependent development were analyzed by three different models depending on ordinary regression method. Campbell et al (1974) as linear model r(T)= a +b.T where r(T) is mean development rate (1/day) at temperature T (°C), a is slope, b is intercept and T is the temperature. Rate of development (1/day) was analyzed by linear and nonlinear model given by Stinner et al (1974) as nonlinear model (C/1+e(a+b.T) where r(T) is mean development rate at temperature T (°C), C is the constant, e is the exponential to the equation and third model was Inverse second order polynomial model [1/D = a/(1 + bT + cT2)] given by Damos and Savopoulou (2021) where D is the days of development and c is constant.

Observations to be recorded: The observations on various biological parameters including fecundity, incubation period, larval period (1st, 2nd, 3rd and 4th instar), pupal period, larval weight, pupal weight, adult longevity, total developmental period, per cent survival of egg, larva and pupa. From the models, Regression coefficient (R^2) and Residual Sum of Square (RSS) were worked out.

RESULTS AND DISCUSSION

The study unveiled significant lowest incubation period in Treatment-5 (35±1°C) at 2.27±0.10 and highest in Treatment-1 (15±1°C) with a duration of 5.24±0.17 days (df=4, f=51.21, *p*=<0.001) (Table 1). The significant lowest duration of first larval instar was recorded in T-5 (35±1°C) with 2.36±0.05 days and highest in T-1 (15±1°C) (df=4, f=32.33, *p*=<0.001). The significant lowest and highest durations of second larval instar was recorded in T-5 (35±1°C) and T-1 (15±1°C) with 3.12±0.04 and 7.30±0.09 days, respectively. Durations of fourth larval instar was lowest in T-5 (35±1°C) lasting for 6.85±0.09 days, whereas the highest was recorded in T-1 (15±1°C) with 13.63±0.06 days. Similarly, the total larval duration was significantly lowest in T-5 (35±1°C), lasting for 16.87±0.28 days and highest was recorded in T-1 (15±1°C) with a duration of 36.52±0.15 days (Table 1).

As insects are ectothermic, their growth, development, and reproduction are primarily influenced by temperature as it plays crucial roles in their metabolism, metamorphosis, mobility, host availability etc. Higher temperatures lead to accelerated metabolic activities in insects, which, in turn, results in a shortened duration of their developmental stages (Shreshta 2019). The findings on larval duration are consistent with the results of Likitha et al (2022) and Shrinivas et al (2019), who observed a total larval period of 25.10±0.99 and 26.10±0.66 days, respectively when the pink bollworm was reared on artificial medium at a temperature of 25±2°C. Additionally, Peddu et al (2019) found that the development of larva increased from 20°C to 35°C and rapidly declined at the temperatures above 35°C. However, the findings are in contrast with earlier results of Rajput et al

Table 1. Effect of constant temperatures on incubation, larval period and total larval duration of *P. gossypiella* in Bt cotton

Sr.No.	Temperature (°C)	Incubation period (days)	Larval period (days)				
			1st Instar	2nd Instar	3rd Instar	4th Instar	Total larval duration
T1	15±1	5.24±0.17 a	5.64±0.02a	7.30±0.09a	9.43±0.05a	13.63±0.06 a	36.52±0.15 a
T2	20±1	4.35±0.20 b	4.56±0.02 b	5.00±0.20b	7.55±0.02b	11.95±0.09 b	29.10±0.13 b
T3	25±1	3.68±0.16 c	3.74±0.04c	4.66±0.02b	5.71±0.03c	10.01±0.08 c	24.24±0.10 c
T4	30±1	3.19±0.12 c	3.12±0.03 d	4.04±0.06 c	5.21±0.09 d	8.79±0.08 d	21.89±0.45 d
T5	35±1	2.27±0.10 d	2.36±0.05 e	3.12±0.04 d	4.16±0.05 e	6.85±0.09 e	16.87±0.28 e
T6	40±1	--	--	--	--	--	--
CD (p=0.05)		0.46	0.11	0.30	0.17	0.25	0.77

Mean of five replications; Data followed by superscript indicate significant differences at as per Tukey's HSD test; Relative humidity = 65±5 per cent; (--) shows 100% mortality

(2018), who reported a maximum fourth instar larval duration of 11.36±0.30 days at 27±2°C.

The male and female pupal duration was recorded lowest in Treatment 5 (35±1°C) and highest in Treatment 1 (15±1°C). The adult longevity of male and female was recorded minimum in Treatment 5 (35±1°C) with 6.44±0.13 and 7.46±0.12 days, respectively and maximum in Treatment 1 (15±1°C) with 9.66±0.23 and 10.40±0.06 days, respectively (Table 2). These align with the observations made by Cacayorin et al (1992) who found that the average duration of pupal stage was 7.42 days. The total developmental period of male and female follows the same trend with the lowest in T-5 (35±1°C), lasting for 25.25±0.50 and 26.24±0.36 days, respectively and highest in Treatment 1 (15±1°C) with duration of 50.65±0.26 and 52.56±0.22 days, respectively (Fig. 1). The findings are supported by Zinzuvadiya et al (2017) who reported that the total developmental period of male was 38.40±4.48 days at 28.34±3.15°C and 49.71±0.50 days at 21°C. Sapna et al (2017) found that the complete life cycle of female from egg to adult emergence was 52.3±6.51 days at 25±1°C. Shrinivas et al (2019) from Raichur, Karnataka, reported that females survived longer than males. An increase in body size and a decrease in development time with respect to increase in temperature are commonly observed outcomes of natural selection acting on individual organisms (Kingsolver et al 2004 and Harrison et al 2013).

Fecundity was significantly lowest in Treatment 1 (15±1°C) with 23.60±0.61eggs per female and significantly higher in Treatment 4 (30±1°C) with 61.30±0.89 eggs per female (df=4, f=22.59, *p*=<0.001) (Fig. 2) and sex ratio was

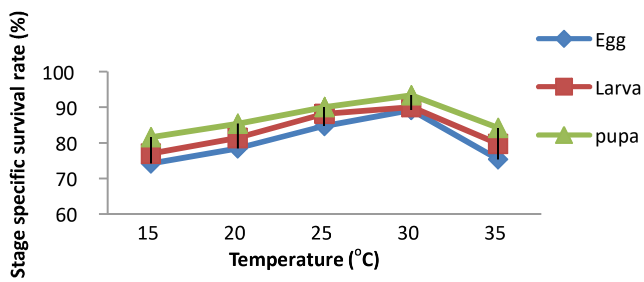

Fig. 1. Effect of constant temperatures on Survival of egg, larval and pupal stages of *P. gossypiella* in Bt cotton

Table 2. Effect of constant temperatures on pupal duration, adult durationand sex ratio of *P. gossypiella* in Bt cotton

Sr. No.	Temperature (°C)	Pupa duration (days) (Mean±SE)		Adult longevity (days) (Mean±SE)		Sex ratio (male:female)
		Male	Female	Male	Female	
T1	15±1	8.88±0.16 [a]	10.80±0.11 [a]	9.66±0.23 [a]	10.40±0.06 [a]	1.50:1
T2	20±1	7.50±0.07 [b]	9.56±0.02 [b]	8.47±0.09[b]	9.99±0.13 [ab]	1.32:1
T3	25±1	7.28±0.09 [b]	8.72±0.04 [c]	7.51±0.11 [c]	9.68±0.12[b]	1.17:1
T4	30±1	6.80±0.21[bc]	8.38±0.26 [c]	7.15±0.06 [c]	9.04±0.06[c]	1:1.08
T5	35±1	6.10±0.26 [c]	7.10±0.13 [d]	6.44±0.13 [d]	7.46±0.12 [d]	1:1.38
T6	40±1	--	--	--	--	--
CD (p=0.05)		0.52	0.42	0.41	1.31	

Mean of five replications; Data followed by superscript indicate significant differences at as per Tukey's HSD test; Relative humidity = 65±5 per cent; (--) shows 100% mortality

Table 3. Effect of constant temperatures on larval weight of first, second, third and fourth instars of *P. gossypiella* in Bt cotton during 2022

Sr. No.	Temperature (°C)	Larval weight (mg) (Mean±SE)			
		1st Instar	2nd Instar	3rd Instar	4th Instar
T1	15±1	2.81±0.02[b]	8.72±0.03 [d]	20.10±0.26 [d]	18.95±0.08 [b]
T2	20±1	2.94±0.04[b]	9.20±0.09[cd]	20.89±0.11 [cd]	19.88±0.26 [ab]
T3	25±1	3.16±0.03[a]	9.68±0.13 [bc]	21.04±0.17 [bc]	20.85±0.41 [ab]
T4	30±1	3.30±0.03[a]	10.07±0.19 [ab]	21.67±0.22 [ab]	21.19±0.27 [a]
T5	35±1	3.36±0.08[a]	10.56±0.33 [a]	22.79±0.23 [a]	21.76±0.32 [a]
T6	40±1	--	--	--	--
CD (p=0.05)		0.14	0.55	0.95	0.72

Mean of five replications; Data followed by superscript indicate significant differences at as per Tukey's HSD test; Relative humidity = 65±5 per cent; (--) shows 100% mortality

recorded highest in Treatment 5 (35±1°C), with sex ratio of 1:1.38 (Table 2). These findings are supported by Hussain et al (2023) who reported that the fecundity of 49.82±1.46 eggs/female at 35°C. Awaknawar (1976) reported a fecundity range of 9-34 eggs per female, with an average of 20.6 eggs per female. Philipp et al (2014) found that the higher the temperature, lower fecundity rates.

The egg, larval and pupal survival was recorded highest in Treatment 4 (30±1°C) with 89.27±0.85, 90.09±0.87 and 93.39±1.12 per cent respectively and lowest in Treatment 1 (15±1°C) (Fig. 3). In the face of extreme heat, numerous insect species struggle to survive, primarily due to their lack of sufficient heat tolerance during gradual heat stress in their natural habitats (Bodlah et al 2023). The alternate temperatures led to elevated overall survival rates in *H. armigera* compared to the survival rates observed under corresponding constant temperatures, (Mironidis et al 2008). This outcome is possibly due to the fact that fluctuating temperatures offer intervals for recovery or enable adaptation to extreme hot or cold conditions (Vargas et al 2000).

The larval weights of first, second, third and fourth larval instars was maximum in Treatment 5 (35±1°C) with 3.36±0.08, 10.56±0.33, 22.79±0.23 and 21.76±0.32 mg, respectively and minimum in Treatment 1 (15±1°C) with 2.81±0.02, 8.72±0.03, 20.10±0.26 and 18.95±0.08 mg, respectively (Table 4). The male and female pupal weight was significantly higher in Treatment 5 (35±1°C) with 10.89±0.42 and 16.90±0.14 mg, respectively. Whereas, the significant lowest was recorded in Treatment 1 (15±1°C)

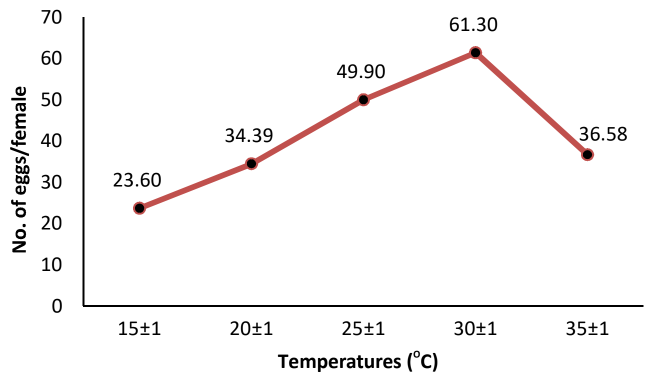

Fig. 3. Effect of constant temperatures on fecundity of *P. gossypiella* in Bt cotton during 2022

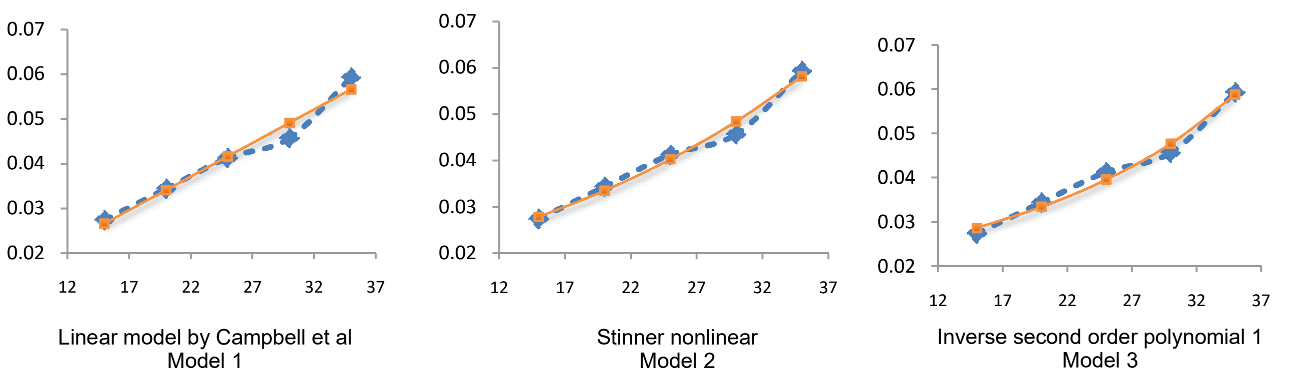

Fig. 4. Fitting different linear and nonlinear models based on development rate (1/day) for total immature larval stage of *P. gossypiella* versus temperature. Blue squares represent observed data

Table 4. Effect of constant temperatures on pupal weight of *P. gossypiella* in Bt cotton during 2022

Sr. No	Temperature (°C)	Pupal weight (mg) (Mean±SE)		Growth Index	
		Male	Female	Larva	Pupa
T1	15±1	9.16±0.18^{b}	15.61±0.14^{bc}	2.10	8.32
T2	20±1	9.34±0.39^{b}	15.81±0.13^{bc}	2.79	10.15
T3	25±1	10.11±0.23^{ab}	15.19±0.16^{c}	3.63	11.33
T4	30±1	10.29±0.18^{ab}	16.23±0.22^{ab}	4.11	12.43
T5	35±1	10.89±0.42^{a}	16.90±0.14^{a}	4.72	12.81
T6	40±1	--	--	--	--
CD (p=0.05)		0.89	0.48		

Mean of five replications; Data followed by superscript indicate significant differences at as per Tukey's HSD test; Relative humidity = 65±5 per cent; (--) shows 100% mortality

Table 5. Regression analysis of three models describing the effect of constant temperature ondevelopment time

Model 1	Parameters	1st Instar	2nd Instar	3rd Instar	4th Instar	Total larval duration
Linear model by Campbell (r(T)= a +b T)	a	-0.015	0.016	0.005	0.015	0.004
	b	0.011	0.008	0.006	0.003	0.001
	R2	0.96	0.94	0.98	0.95	0.96
	RSS (x10^{-4})	13.84	9.165	1.891	1.502	0.196
Model 2						
Stinner nonlinear model (C/1+e(a+b.T)	a	3.205	3.285	3.424	3.896	4.786
	b	-0.051	-0.041	-0.042	-0.037	-0.037
	c	2.12	2.257	1.881	2.054	1.921
	R2	0.98	0.95	0.98	0.98	0.98
	RSS (x10^{-4})	3.90	7.90	1.96	0.05	0.10
Model 3						
Stinner nonlinear model (1/D = a/(1 + bT + cT2)	a	8.376	14.378	11.605	17.977	18.126
	b	-0.200	-0.570	-0.550	-0.283	1.378
	c	0.001	0.007	0.006	-0.001	-0.0406
	R2	0.99	0.93	0.98	0.99	0.88
	RSS (x10^{-4})	0.991	13.53	2.02	0.13	0.65

Comparison between linear and non-linear models shows close relation between development rate and temperature for 1st , 2nd instar and overall larval development

weighing 9.16±0.18 and 15.61±0.14 mg, respectively (Table 5). The larval and pupal growth index was higher in Treatment 5 (35±1°C) and lowest in Treatment 1 (15±1°C) (Table 5).The recent observations regarding the larval weight of the pink bollworm align with previous research conducted by Dharajothi et al (2016) and found larval weight of 21.40±3.63 mg at 27±0.5°C. These results are consistent with the observations made by Fand et al (2019) who reported larval weight of 21.96 mg when fed on bolls of Bt cotton.

Correlation between developmental parameters like incubation period, larval duration, pupal duration, adult longevity and total developmental period has shown significant negative correlation with constant temperatures. Different temperature based model studied by various scientist on different lepidopteran. The development rate of *Spodoptera litura* when predicted for linear and non-linear models showed that thermodynamic SSI non-linear and Lactin-2 models were most fitted and estimated 34.5°C and 33.7°C, respectively as best suited for its development (Prasad et al 2021). Similarly Damos and Savopoulou (2021) advised that for particular specie there is an inverse relation between development of specie and threshold temperature that fitted the model.

CONCLUSION

It can be concluded that the shortest duration of *P. gossypiella* was recorded at constant temperature of 35±1°C and increased with decrease in temperature. The larval and pupal weight of *P. gossypiella* were highest at constant temperature of 35±1°C. An increase in body size and a decrease in development time with respect to increase in temperature are commonly observed outcomes of natural selection acting on individual organisms. The fecundity and per cent survival of *P. gossypiella* were highest at constant temperature of 30±1°C and decreased with both rise and fall of temperature. All the developmental parameters showed highly significant negative correlation with constant temperature. Including forecasting model in relation to different temperature will help in timely prediction of any outbreak and sustainable management.

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Varietal Screening of Stored Pigeonpea for Resistance to Seed Beetle, *Callosobruchus maculatus* (F.)

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***Abstract*:** Ten varieties of pigeonpea were assessed for their relative susceptibility to seed beetle *Callosobruchus maculatus* (F.), in storage under no-choice and free-choice conditions during 2022-23. Under no-choice condition, the variety LRG 133-33 recorded maximum emergence (116.0 adults) and grain damage (62.67%), while LRG 467 had the least values for adult emergence and grain damage (56.33 no. and 32.33%, respectively). Under free-choice condition also, LRG 467 showed significantly higher level of resistance against seed beetle allowing very less emergence (50.33 adults) with minimum grain damage (34.67%) compared to other varieties. The resistance reaction of LRG 467 variety against *C. maculatus* was further confirmed in dual-choice test, wherein the number of adults emerged was lower (79) against LRG 133-33 (104). The seed beetle took slightly longer period for egg to adult emergence on LRG 467 (23.92 days) compared to LRG 133-33 (22.73 days) indicating the interference of some secondary metabolites in larval growth and development of the insect.

Keywords: Pulses, Storage insects, Bruchid, Relative susceptibility

Grain legumes play a pivotal role in ensuring nutritional security for the millions of Indian population, as they are rich in proteins, fibres and several essential nutrients, amino acids, minerals, and certain vitamins. India is the world's largest producer and consumer of a wide variety of grain legumes, hence they play an important role in Indian economy. Chickpea, pigeonpea, blackgram and greengram are the major grain legumes cultivated in Andhra Pradesh, and a total of 78 thousand tonnes of pigeonpea was produced from an area of 2.42 Lakh ha during 2022-23 (Division of Economics and Statistics 2023). Grain legumes are stored at various levels in various quantities for various purposes; sowing, consumption, processing, marketing *etc*., for shorter or longer duration, during which they suffer great damage due to insect attack. The cowpea weevil *Callosobruchus maculatus* (F.), is the most predominant destructive pest of stored grain legumes in Andhra Pradesh which can inflict huge losses in terms of quantity and quality (Harika et al 2023). Though insecticides were much relied for their control, reduced susceptibility of the bruchid populations to the commonly used insecticides malathion and deltamethrin (Sarada et al 2021) necessitated search for the alternative methods such as the use of modified atmospheres, hermetic packaging, plant powders *etc* (Swamy and Rao 2016, Swamy and Wesley 2017, Harika et al 2024). Nevertheless, a superior field performing variety, if susceptible to storage insect pests, often results in huge losses. Hence, development and use of resistant pigeonpea cultivars offers a simple, cheap and attractive approach for successful preservation of grain legumes from bruchid attack in an environment-friendly manner (Keneni et al 2011). With this in view, experiments were conducted to know the relative susceptibility of pigeonpea varieties against seed beetle.

MATERIAL AND METHODS

A total of 10 varieties of pigeonpea obtained from Regional Agricultural Research Station, Lam, Guntur, Andhra Pradesh were evaluated for resistance to seed beetle in storage under no-choice and free-choice conditions during 2022-23.

Insect culture and bioassays: Seed beetle, *C. maculatus* insects required for the experiments were cultured on pigeonpea grains obtained from freshly harvested crop and was maintained at ambient room temperature and relative humidity. Before their use in experiments, all the pigeonpeas were disinfested by fumigation with phosphine for seven days to remove inherent field infestations, if any. The moisture of test grains was ranged between 9.30 and 9.96 %.

No-choice test: Pigeonpea grains (40 g of each variety) were taken in plastic containers (200 ml capacity) and five pairs of freshly emerged *C. maculatus* beetles were released and secured with a lid. After allowing oviposition for five days, the adults were removed and data on number of eggs per 100 seeds were recorded. Subsequently, they were observed for the progeny emergence at 40 and 60 at days after release of insects (DAR) and pooled to express as total number of adults emerged. The per cent grain damage was recorded at 60 DAR.

Free-choice test: Pigeonpea grains (20 g each) were taken in shallow cups and arranged in a circle in a wide plastic tray (l

× b × h: 45 cm × 45 cm × 10 cm) and a total of 100 seed beetles (mixed population) were released in the center to allow free movement of adults among the grains of their choice. The tray was closed with another tray of same size by keeping in reverse position and tightly securing with binder clips. The set up was kept undisturbed for five days to allow oviposition by the female insects, later the grains along with insects were transferred individually into plastic jars (200 ml). Data on number of eggs per 100 seeds at 10 DAR were recorded and allowed for subsequent development. The numbers of progeny adult emergence were observed at 30 and 45 DAR and expressed as total number of adults. Per cent grain damage was also recorded at 45 DAR.

Dual-choice test: The variety which showed maximum resistance to seed beetle in the above experiments was compared with another variety that showed susceptible reaction under dual-choice condition. For this, 100 grains of both pigeonpea varieties were taken in separate cups and placed in the insect cage (l × b × h: 20 cm × 15 cm × 15 cm), and 20 newly emerged beetles were released in the middle of two cups. Thus, six replications were set up. They were confined for 24 hours allowing oviposition by females. The insects were removed from the grains and transferred in to separate containers. Later after three days, individual single egg laden grains from each variety were collected and kept in glass vials. They were observed daily till the adult emergence to note the number of days taken for an egg to develop into adult stage. Thus, total number of adults emerged and the period from egg stage to adult emergence was recorded.

Statistical analysis: All the experiments were conducted at ambient conditions. Both no-choice and free-choice experiments were conducted by adopting completely randomized block design replicating thrice. The data were suitably transformed and subjected to analysis of variance (ANOVA) using web-based agricultural statistics software package WASP 2.0 to test their significance.

RESULTS AND DISCUSSION

Under no-choice condition, though LRG 486 had the highest number of eggs (13.67) and LRG 52 had the least (1.0) per 100 grains and was reflected in adult emergence (Table 1). The variety, LRG 133-33 recorded maximum emergence (116.0 adults) and grain damage (62.67%), while LRG 467 had the least values for adult emergence and grain damage (56.33 adults and 32.33%, respectively). Under free-choice condition also, LRG 467 consistently showed significantly higher level of resistance against seed beetle allowing very less emergence (50.33 adults) with minimum grain damage (34.67%) compared to other varieties. However, LRG 133-33 recorded the maximum emergence (159.67 adults) that inflicted 62.67% grain damage. The resistance reaction of LRG 467 variety against *C. maculatus* was further confirmed in dual-choice test, wherein the number of adults emerged was lower (79) against LRG 133-33 (104). The seed beetle took slightly longer period for egg to adult emergence on LRG 467 (23.92 days) compared to LRG 133-33 (22.73 days) (Fig. 1) indicating the interference of some secondary metabolites in larval growth and development of the insect.

Satheesh et al (2021) also considered the parameters like growth index (GI), egg number and adult emergence for evaluating resistance in pigeonpea genotypes. Among different species of grain legumes tested, Mostafa et al (2023) observed longer developmental time of cowpea beetle fed on broad bean with the minimum immature survival rate, while Bidar et al (2021) observed longest

Table 1. Preference and development of seed beetle on different pigeonpea varieties

Variety	No-choice conditions			Free-choice conditions		
	Eggs (No.)/ 100 grains	Adult emergence (No.)	Grain damage (%)	Eggs (No.)/ 100 grains	Adult emergence (No.)	Grain damage (%)
LRG 52	1.0	67.67	34.0	34.33	86.33	47.67
LRG 105	3.33	95.33	50.67	37.33	144.67	66.0
LRG 133-33	5.33	116.0	62.67	53.33	159.67	71.67
LRG 223	1.33	97.33	45.33	38.0	115.67	50.33
LRG 454	6.0	87.33	39.0	37.0	125.33	68.0
LRG 467	2.0	56.33	32.33	24.0	50.33	34.67
LRG 471	6.67	88.0	42.67	35.0	90.33	45.67
LRG 486	13.67	79.33	36.33	31.67	129.33	65.0
LRG 492	4.33	89.33	44.67	38.33	107.67	65.33
LRG 499	5.67	74.0	38.67	30.0	115.67	66.33

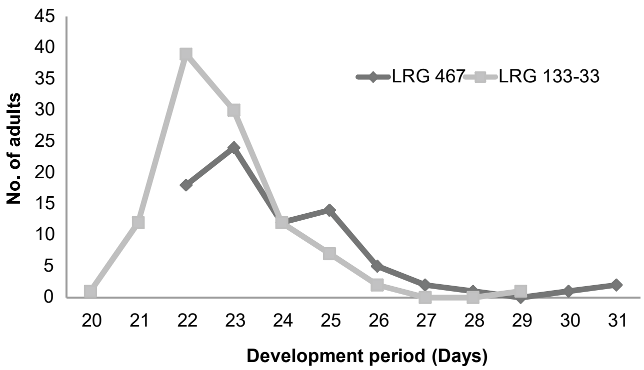

Fig. 1. Pattern of seed beetle adult emergence on LRG 467 and LRG 133-33

developmental time on lentil. The chickpea varieties; NBeG 458, NBeG 47 and KAK 2 with thin seed coat and larger seed size recorded higher oviposition, adult emergence and grain damage (Swamy et al 2020). Pigeonpea genotypes having the traits like hard seed with less seed diameter and high proportion of seed coat are less preferred by the bruchids (Satheesh et al 2021). In contrast, a pigeonpea landrace namely IC 637089, though found moderately resistant to *Callosobruchus chinensis*, seed physical characters did not show any significant effect on any of the insect biological parameters indicating the role of biochemicals (Saravanan et al 2023). Chandel and Bhadauria (2015) reported that pigeonpea varieties; Jagarti, PUSA-33, ICPL-151, PUSA-84, UPAS-120 and Type 7 had significantly poor emergence of *C. chinensis* beetles and found it was positively governed by the test weight, hardness and moisture content of the seeds, though non-significant. However, the emergence of the adults was reduced by the increase in protein content in the seeds.

CONCLUSION

Among the pigeonpea cultivars tested, LRG 467 with minimum adult emergence and longer developmental period is found resistant to seed beetle infestation. The exact factors offering resistance are to be further explored for better understanding of the resistance mechanism. In view of the storage losses due to seed beetle, any sort of resistance available in the varieties may be useful in securing pulses seed and also as sources in crop improvement programme.

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Natural Enemies of Lac Insect, *Kerria lacca* (Kerr) in Sub-humid Sutlej-Ganga Alluvial Plains of India

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Abstract: Surveys were conducted in various districts of Punjab, Delhi and Uttar Pradesh to record the diversity of natural enemies (predators and parasitoids) associated with lac insect (*Kerria lacca*) during 2019 to 2023. A total of 8 natural enemies including four predators, *Eublemma amabilis* Moore, *Pseudohypatopa pulverea* (Mayrick), *Chrysoperla zastrowi sillemi* (Esben-Peterson), *Tribolium* sp., and four parasitoids, *Aprostocteus purpureus* (Cameron), *Tachardiaephagus tachardiae* (Howard), *Tyndarichus clavicornis* (Cameron), *Eupelmus tachardiae* (Howard) were associated with lac insect. Besides these, one hyper-parasitoid, *Bracon greeni* Ashmead was also recorded. Among these, *E. amabilis* was the predominant species. The study will help in planning effective management practices to tackle these biotic stresses in lac cultivation.

Keywords: Predators, Parasitoids, Hyperparasitoid, Lac, *Kerria lacca*

Lac is natural, renewable, non-toxic, bio-degradable and eco-friendly resin, being secreted by a tiny scale insect, *Kerria lacca* (Kerr). Lac is mainly produced in tropical Asian countries namely India, Thailand, Indonesia, China, Myanmar, Philippines, Vietnam and Cambodia. Among these, India is the leading producer of lac in the world. In India, lac cultivation is an important source of income for livelihood of the forest and sub-forest inhabitants in different states like Jharkhand, Chhattisgarh, Madhya Pradesh, West Bengal, Odisha, Uttar Pradesh, Telengana, Andhra Pradesh, Gujarat and North Eastern states. Out of the nine genera and 99 species of lac insects reported worldwide, 2 genera and 26 species are found in India out of which *K. lacca* is the most widely available species in the country (Ahmad et al 2013). Lac insects are mostly confined to woody dicotyledonous group of Angiosperms. More than 400 plant species have been found associated with lac insects worldwide. Out of these, about 113 host species are known to be successfully infested by lac insect in India. The natural infestation of lac insect has been recorded on 15 host plants (Sangha et al 2019; Shera et al 2021).

The losses due to biotic and abiotic stresses are the major constraints that pose a substantial challenge in lac cultivation. Several natural enemies from diverse groups (predators and parasitoids) belonging to orders Lepidoptera, Neuroptera, Coleoptera and Hymenoptera have been reported against lac insect thereby causing 30-40 per cent losses to the lac yield (Sharma et al 2006, Jaiswal et al 2008). Various management strategies including cultural and physical control (Bhattacharya et al 2006), biological control (SiMing et al 2010), and chemical control (Singh et al 2009) have been utilized to restore yield loss owing to predators and parasitoids. The present study was therefore conducted to explore the diversity of natural enemies in in Punjab, Delhi and Uttar Pradesh so that an effective integrated management strategy can be devised for these natural enemies so as to achieve optimum lac yield potential.

MATERIAL AND METHODS

Surveys were conducted in various districts of Punjab, Delhi and Uttar Pradesh for five years to document the insect fauna associated with lac insect during 2019 to 2023. The lac encrusted sticks (brood sticks) were collected randomly during both rainy season (*Katki* crop) and summer season (*Baisakhi* crop), in five replications, and these samples were kept in specially designed bioagent collection cages (20 x 20 x 30 cm) fitted with glass tubes. These cages were monitored twice a week to record the emergence of parasitoids and predators from the lac sticks. The samples of parasitoids and predators were preserved in ethyl alcohol and were got identified from ICAR- National Institute of Secondary Agriculture, (NISA), Ranchi. To calculate the diversity or dominance of individual parasitoids and predators collected, the data on number of individuals were subjected to computation as per Shannon and Weiner diversity index (1963), Pielou evenness index (1966) and Southwood dominance index (1978).

RESULTS AND DISCUSSION

The total of eight natural enemies including four predators, four parasitoids and one hyperparasitoid were associated with lac insect. Among predators, four species namely *Eublemma amabilis* Moore (23.38%), *Pseudohypatopa pulverea* (Mayrick) (12.95%), *Chrysoperla zastrowi sillemi* (Esben-Peterson) (11.33%), and *Tribolium* sp. (15.29%) were recorded. There were four parasitoids, *viz*. *Tachardiaephagus tachardiae* (Howard) (14.75%), *Aprostocteus purpureus* (Cameron) (11.33%), *Eupelmus tachardiae* (Howard) (1.98%), and *Tyndarichus clavicornis* (Cameron) (0.90%). Besides these, one hyper-parasitoid, *Bracon greeni* Ashmead (Braconidae: Hymenoptera) was also recorded. Among these, *E. amabilis* was the predominant species (Table 1). The number of insect parasitoids and predators belonging to order Hymenoptera, Lepidoptera, Coleoptera and Neuroptera were observed during the study. The abundance of parasitoids and predators belonging to these was: Hymenoptera (37.05%)> Lepidoptera (36.33%) > Coleoptera (15.29%)> Neuroptera (11.33%). Similarly, the relative abundance of natural enemies' families associated with lac insect were Noctuidae (24%) > Encyrtidae (18%) > Tenebrionidae (15%) >Blastopidae (13%) > Eulophidae (11%) > Chrysopidae (11%) > Braconidae (8%). The index of species diversity and index of dominance indicated that the natural population of associated natural enemies was found to be maximum in the year 2023 and minimum in the year 2019 and 2022. Species richness and Simpson's index was found to be maximum in the year 2022. On the contrary, species evenness was highest in the year 2019 and 2022 and lowest in 2023 (Table 2).

Several predators and parasitoids have been reported to be associated with lac insect which is in agreement with the present studies. Meena and Sharma (2018) described 11 insect species from 8 families associated with *K. lacca* under which 3 were predator species (*E. amabilis, P. pulverea*, and *C. zastrowi*), 4 primary parasitoids (*T. tachardiae, A. purpureus, T. clavicornis, E. dewitzi*) and 4 hyperparasitoids (*A. fakhrulhajiae, E. tachardiae, B. greeni, B. tachardiae*) in western plains of India. The lepidopteran predators, *E. amabilis* and *P. pulverea* have been reported to be key natural enemy of lac insect causing damage to lac encrustations across India (Rahman et al 2009; Chattopadhyay 2011; Sharma and Ramani 2011). Bhattacharya et al (2007) and Jaiswal et al (2008) also stated that *E. amabilis* and *P. pulverea* are the two dominant predators of lac insect causing 20 to 40 per cent losses to lac crop. Daharia and Katlam (2013) also reported the dominance of these two predators in Chhatisgarh state.

Table 1. Natural enemies associated with lac insect, *Kerria lacca* (Kerr) in Sub-humid Sutlej-Ganga Alluvial Plains of India during 2019-2023

Scientific name	Order	Family	Relative abundance (%)
Predators			
Eublemma amabilis Moore	Lepidoptera	Noctuidae	23.38
Pseudohypatopa pulverea (Mayrick)	Lepidoptera	Blastopidae	12.95
Chrysoperla zastrowi sillemi (Esben-Peterson)	Neuroptera	Chrysopidae	11.33
Tribolium sp.	Coleoptera	Tenebrionidae	15.29
Parasitoids			
Tachardiaephagus tachardiae (Howard)	Hymenoptera	Encyrtidae	14.75
Aprostocteus purpureus (Cameron)	Hymenoptera	Eulophidae	11.33
Eupelmus tachardiae (Howard)	Hymenoptera	Encyrtidae	1.98
Tyndarichus clavicornis (Cameron)	Hymenoptera	Encyrtidae	0.90
Hyper-parasitoid			
Bracon greeni Ashmead	Hymenoptera	Braconidae	8.09

Table 2. Diversity indices of arthropod fauna associated with lac insect, *Kerria lacca* (Kerr) during 2019-2023

Year	Species richness	Index of species diversity	Evenness index	Index of dominance	Simpsons index
2019	1.12	0.04	0.96	0.04	4.81
2020	1.40	0.14	0.86	0.14	5.13
2021	0.76	0.05	0.95	0.05	4.43
2022	1.45	0.04	0.96	0.04	7.02
2023	0.97	0.27	0.73	0.27	2.61
Over all	1.27	0.09	0.91	0.09	6.77

Likewise, *Chrysoperla* spp. from chrysopidae family has also been reported to be important predator of lac insect in India (Sharma et al 2006, Ramesh 2013, Rajpoot et al 2020).

Among parasitoids, *T. tachardiae* and *A. purpureus* were dominant species in the present studies (Sharma et al 2010, Chattopadhyay 2011, Monobrullah et al 2015). Yogi and Bhattacharya (2015) documented 72 parasitoids and predators, out of which predator *E. amabilis* and parasitoids *T. tachardiae* and *A. purpureus* were the dominant ones.

CONCLUSION

The present studies thus revealed a rich fauna of natural enemies associated with lac insect. There is need to adopt proper management practices to tackle these biotic stresses so as to avoid huge losses to lac cultivation.

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AUTHORS CONTRIBUTION

PS Shera and KS Sangha involved in conceptualization, planning, and manuscript editing; S Sharma and R Kaur contributed in execution of work; Arshdeep Singh, Ankita Thakur and Shasta Kalra involved in data collection, analysis and draft writing. All authors read and approved the manuscript for publication.

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Mass Multiplication and Shelf-life Study of Talc-Based Bioformulation of *Bacillus subtilis* B4: in Hot and Semi-Arid Zone

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***Abstract*:** Biocontrol agents such as *Bacillus subtilis* are widely used against soil-borne plant pathogens. Mass production and shelf life are crucial for the commercial success of bioformulation against plant pathogens. The microbial cfu count declined with an increase in the storage time. The talc-based bioformulation of *Bacillus subtilis* B4 was evaluated for shelf life at different temperatures (ambient, 25°C, 4°C and 0°C) in the polythene bags. The initial microbial count for the bacterial antagonist i.e. *B. subtilis* B4 the initial inoculum density at zero day was 8.3×10^{10} which gradually decreased to 3.4×10^{4} after 360 days at ambient temperature. Still, the decline was not so prominent at 0°C after 360 days (7.1×10^{5}). There was a significant interaction between temperature and storage time Treatment combinations (T: Temperature; M: Month) T_1M_0, T_2M_0, T_3M_0 and T_4M_0 i.e. 8.3×10^{10} cfu/g, exhibited significant counts as compared to other treatments combinations. Storage of talc-based bioformulation of *B. subtilis* B4 at 4°C and 0°C was more suitable than storage at 25°C and ambient temperature. The current findings indicated that to maintain the spore viability and effective threshold density above 10^{6} Cfu/g (colony forming units/g of formulation) at ambient for six months. However, the effective cfu count (10^{6} Cfu/g) of *B. subtilis* was maintained for 11 and 9 months at freezing (0°C) and at 4°C temperatures, respectively.

Keywords: *Bacillus subtilis*, Shelf life, Talc, Bioformulation

During the Green Revolution, an intensification in agriculture was done to meet the increasing demands for food and fibre globally (Sharma et al 2014). Because of this in the last two to three decades, rampant chemical fertilization posed a threat to the health of all living beings and destroyed the soil health which led to the reduction of Indigenous beneficial soil microbes (Pathak et al 2022) and unstable crop responses coupled with the development of resistance in the pathogens (Choudhary et al 2022). An alternative green approach requires time to maintain farm productivity without chemical dependency. In view of organic farming and sustainable agriculture, there is a need to investigate for successful biological control (Gade and Lad 2018). Biological control is the use of unambiguous microbes that intervene with various mechanisms of plant pathogens and pests (Choudhary et al 2023). Till date, several bacterial and fungal biocontrol control agents (BCAs) are registered and are available as commercial products (Choudhary et al 2021). Microbial bio formulations offer an alternative way to attain better plant growth and productivity (Ayilara et al 2023). The use of beneficial microbes in the greenhouse is fine but under field conditions, their viability issue gets enhanced. To get positive results from a bioformulation, a significant number of living microbial cells ($\approx 10^{6}$) is needed (Vassilev et al 2020) which leads to the commercial success of the formulated product through consistent field responses (Saikia et al 2023). Therefore, a potent bioagent must possess propagules that must remain viable with a good shelf life. The shelf life varies widely with microbial species, water availability, storage time and temperature and production methods etc. *Bacillus subtilis*, is known for the production of bioactive metabolites and siderophores, in addition to nutrient solubilization (Bora and Bora 2021). *Bacillus* spp. are effective against various diseases of crops like wheat, sugarbeet, sweet potato, etc. are widely reported (Bora et al 2024). In the present study, the objective was to isolate *Bacillus* species with potent antagonistic activity, to prepare bioformulations and to study their shelf-life for 360 days from the date of manufacturing at a regular interval of 30 days.

MATERIAL AND METHODS

Site specifications: This study was conducted at Biocontrol Laboratory, Department of Plant Pathology, Punjab Agricultural University, Ludhiana during 2021-22. The site is located in the South-Western zone of Punjab having latitude and longitude of 30°54' N, 75°48' E, respectively -above the mean sea level of 247 meters.

Isolation and identification: *Bacillus subtilis* B4 was isolated from soil sample adhered to potato roots by dilution plate technique and was maintained on MYP Agar media (Mannitol egg Yolk Polymyxin agar, HiMedia). The identification of species was done using *Bacillus* spp. specific primers Bsub5F and Bsub3R (Singh and Chaudhari 2012) and the sequence was submitted to NCBI GenBank to obtain its accession number (ON479713).

Preparation of the bioformulation: During bioformulation preparation, the sterilization of talc (magnesium silicate) was done by autoclaving at the temperature of 121°C for 30 min (Khan et al 2023). Bacterial suspensions were produced on NB (Nutrient Broth). 500ml of this bacterial broth culture was added to the 1kg of sterilized talc powder under aseptic conditions. 1% CMC (carboxymethylcellulose) was added to the mixture as an adjuvant before packing it in the sterilized polythene bags (Choudhary et al 2021) and stored at ambient (5-45°C), 25°C and 4°C and 0°C for checking the shelf life of bioformulation.

Shelf life of bioformulation: The vivacity of bacterial cultures in the formulation was confirmed by the serial dilution plating method. One gram of formulation was added to 9 ml of sterilized water. Dispersing agents like Tween-20 were added for their uniform distribution (Singh et al 2021). One ml formulated bioproduct which was serially diluted to 10^{-13} was transferred to the freshly prepared Nutrient Agar plates and then incubated at 28 ± 1°C. The population counts of *B. subtilis* B4 were made at zero day and then at every one-month interval for 12 months. Plating was done in triplicates and the final CFU/mL was the average of three readings used to represent viable bacterial count (Maheshwari et al 2015). The shelf life of the formulations during the storage period was expressed as log10 Cfu g^{-1} (Mulatu et al 2021).

Statistical analysis: Cfu values of *B. subtilis* was analysed using IBM SPSS Statistics 29.0.2.0

RESULTS AND DISCUSSION

The population of *B. subtilis* B4 remained at a higher density and the gradual decrease was observed at different storage conditions. Significantly higher value was in M_0 ($8.3×10^{10}$ cfu/g) followed by M_1T_1 ($6.2×10^9$ cfu/g) and the lowest count was recorded in $M_{12}T_1$ ($3.4×10^4$ cfu/g) (Table 1). The interaction of temperature and storage time (T×M) on microbial count was also significant. Treatment combinations

Table 1. Shelf life of *Bacillus subtilis* B4 isolates in talc powder-based bioformulation

Storage period*(Days)	Cfu/g of bioformulation /temperature				Mean
	T_1 (Ambient) 5°C - 45°C	T_2 25°C	T_3 4°C	T_4 0°C	
M_o (0 days)	$8.3 × 10^{10}$ (25.14)	$8.3 × 10^{10}$ (25.14)	$8.3 × 10^{10}$ (25.14)	$8.3 × 10^{10}$ (25.14)	$8.3 × 10^{10}$ (25.14)
M_1 (30 days)	$6.2 × 10^9$ (22.55)	$6.9 × 10^9$ (22.65)	$8.8 × 10^9$ (22.90)	$7.3 × 10^{10}$ (25.01)	$2.3 × 10^{10}$ (23.28)
M_2 (60 days)	$5.8 × 10^8$ (20.18)	$6.7 × 10^8$ (20.32)	$7.2 × 10^9$ (22.70)	$6.1 × 10^{10}$ (24.83)	$1.7 × 10^{10}$ (22.01)
M_3 (90 days)	$7.1 × 10^7$ (18.08)	$7.4 × 10^7$ (18.12)	$6.9 × 10^8$ (20.35)	$8.8 × 10^9$ (22.90)	$2.4 × 10^9$ (19.86)
M_4 (120 days)	$6.9 × 10^6$ (15.75)	$7.2 × 10^7$ (18.09)	$6.3 × 10^8$ (20.26)	$8.6 × 10^9$ (22.88)	$2.3 × 10^9$ (19.24)
M_5 (150 days)	$5.4 × 10^6$ (15.50)	$4.6 × 10^7$ (17.64)	$3.2 × 10^8$ (19.58)	$7.9 × 10^9$ (22.79)	$2.0 × 10^9$ (18.88)
M_6 (180 days)	$3.2 × 10^6$ (14.98)	$2.4 × 10^7$ (16.99)	$2.7 × 10^8$ (19.41)	$4.1 × 10^9$ (22.13)	$1.0 × 10^9$ (18.38)
M_7 (210 days)	$8.0 × 10^5$ (13.59)	$4.2 × 10^6$ (15.25)	$1.2 × 10^8$ (18.60)	$8.8 × 10^8$ (20.60)	$2.5 × 10^8$ (17.01)
M_8 (240 days)	$4.7 × 10^5$ (13.06)	$3.9 × 10^6$ (15.18)	$7.7 × 10^7$ (18.16)	$4.7 × 10^8$ (19.97)	$1.3 × 10^8$ (16.59)
M_9 (270 days)	$8.3 × 10^4$ (11.33)	$1.9 × 10^6$ (14.46)	$5.4 × 10^6$ (15.50)	$6.5 × 10^7$ (17.99)	$1.8 × 10^7$ (14.82)
M_{10} (300 days)	$5.9 × 10^4$ (10.99)	$4.8 × 10^5$ (13.08)	$6.7 × 10^5$ (13.42)	$7.6 × 10^6$ (15.84)	$2.2 × 10^7$ (13.33)
M_{11} (330 days)	$4.6 × 10^4$ (10.74)	$7.4 × 10^4$ (11.21)	$4.2 × 10^5$ (12.95)	$2.9 × 10^6$ (14.88)	$8.6 × 10^6$ (12.44)
M_{12} (360 days)	$3.4 × 10^4$ (10.43)	$6.6 × 10^4$ (11.10)	$3.9 × 10^5$ (12.87)	$7.1 × 10^5$ (13.47)	$3.1 × 10^6$ (11.97)
Mean	$9.3 × 10^9$ (15.56)	$1.0 × 10^{10}$ (16.86)	$1.1 × 10^{10}$ (18.60)	$2.6 × 10^{10}$ (20.65)	-
LSD $_{0.05}$	T (Temperature) M (Month) T × M		0.18 0.08 0.14		

Figures in parentheses are log-transformed values

T_1M_0 (T: Temperature; M: Month), T_2M_0, T_3M_0, and T_4M_0 (8.3×10^{10} cfu/g) exhibited higher counts as compared to other T × M combinations. The minimum count was noticed in T_1M_{12} (3.4×10^{4} cfu/g). The population decline continued for 12 months, with fast decline observed at ambient and 25°C and slow decline at 4 °C and 0°C. The freezing temperature acted as best for long-term storage throughout the year with a last count of 7.1×10^{5} cfu/g of bioformulation. Chung *et al* (2010) also observed that bioformulation of *B. subtilis* strain AH8 and *B. licheniformis* strain K11 showed cfu count of 5.8×10^{9} which remained the same up to 60 days at 45°C. Similarly, Gupta and Dohroo (2014) found that the talc-based formulations of *Bacillus subtilis* had an initial count of 2.0×10^{8} at zero day which was reduced to 8.3×10^{6} cfu/g after 80 days of storage at ambient temperature. Narasimhan and Shivakumar (2015) revealed that the population level of *B. subtilis* was stabled in talc-based formulation with cfu count of 1.6×10^{8} at 30°C and remained the same until 180 days of storage. Martinez *et al* (2016) proved that a talc-based powder formulation of *B. cereus* strain B25 spores with cfu 1.1×10^{9} spore count and its viability in the powder formulation decreased slowly over time after 360 days of storage at room temperature. Jayasudha *et al* (2017) reported vermiculite and talc-based bioformulation of *B. subtilis* strain KK-9A recorded the highest number of colonies forming unit examined at fifteen days intervals up to three months of storage. Naveesh et al (2022) and Sinha et al (2004) demonstrate the suitability of talc as a carrier for maintaining the efficacy of microorganisms during storage. Successful management of plant disease by biocontrol agents depends on the availability of effective bioformulations, their rapid multiplication, colonization after inoculation and most importantly survival during storage conditions.

CONCLUSION

Successful management of plant disease by biocontrol agents directly depends upon the availability of effective bioformulations, their rapid multiplication, colonization after inoculation and most importantly survival during storage conditions. The present study concluded that there was a general decline in the number of cfu's with increasing storage time at different temperatures. The storage of talc-based bioformulation of *Bacillus subtilis* at 4°C and 0°C was more suitable than storage at 25°C and ambient temperature..

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Management of Wheat Powdery Mildew using Cow Urine based Plant Extracts

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Abstract: Wheat powdery mildew (PM) caused by *Blumeria graminis* f.sp. *tritici* (*Bgt*) is a disease of global occurrence and importance inflicting huge reduction in yield. Most of the varieties, grown commercially in epidemiologically important areas of India, are susceptible to it and application of fungicides provide a short-term effective means for its management. In present study cow urine-based leaf extracts of eight commonly available plants were evaluated for the management of the disease under *in vitro*, greenhouse and field conditions during 2018-19 at CSK Himachal Pradesh Agricultural University, Palampur, a hot spot for the disease. All the treatments resulted in significantly less spore germination at 5 to 20 per cent concentration as compared with no treatment check. Maximum spore germination inhibition of 78.87, 73.01 and 71.35 per cent was recorded in plant extract of *Azadirachta indica, Calotropis gigantia* and *Justicia adhatoda*, respectively under *in vitro* conditions. The interaction effects of concentration and treatments were significant at 72 hoursof incubation which indicated that treatment effect varied with the concentration. *A. indica* @ 20 per cent was highly effective both as preventive and curative treatment as foliar sprays under greenhouse conditions. The least per cent disease index (PDI) of 19.05 per cent with disease control of 85.28 per cent was recorded in leaf extracts of *C. gigantia* followed by *J. adhatoda* (21.39%) and *A. indica* (25.74%). The highest grain yield of 34.63 q/ha with 39.82 per cent increase over the untreated check was with *C. gigantia* followed by *J. adhatoda* and *A. indica*. The highest net profit of Rs.14649 per ha with cost benefit ratio of 1:5.2.

Keywords: Eco-friendly management, Plant extracts, Wheat, Powdery mildew, *Blumeria graminis tritici*

Powdery mildew (PM), caused by *Blumeria graminis* f.sp. *tritici* (*Bgt*) is a widely prevalent disease of wheat (*Triticum aestivum* L.) causing severe yield losses ranging from 13-34 and 50-100 per cent under low or moderate infection and severe disease pressure, respectively (Basandrai and Basandrai 2017, Vikas et al 2020). The disease has become a potential threat in north western plain zone (NWPZ) and north hill zone (NHZ) with the wide spread cultivation of varieties with powdery mildew resistant gene *Pm8* due to emergence, and fast spread of matching virulences. Most of the present day commercially grown varieties in these areas are susceptible to it (Crop-Protection-Report2022-23_compressed.pdf (aicrpwheatbarleyicar.in)) and there is no breeding program specifically aimed at development of PM resistant varieties. Chemical fungicides have been used successfully for the management of fungal diseases of plants including wheat powdery mildew. However, use of fungicides is being discouraged worldwide due to their hazardous effects on human health, environment, soil, water and development of fungicidal resistant strains of the pathogen (Mehta et al 2022). It is now obligatory and compelling to identify viable alternatives and eco-friendly approaches for the management of various diseases including wheat PM (El-Mougy et al 2004, Naz et al 2018). Extensive research has been undertaken for environmentally safe and easily bio-degradable bio-fungicides and plant extracts. Some of Plant extracts (PEs) have gained popularity and scientific interest for their antibacterial and antifungal activities (Santas et al 2010). Moreover, PEs degrade quickly and have short pre-harvesting intervals and less residual effects (Naz et al 2018). These have been found to be effective in plant disease management and may be safely incorporated as fast-acting and non-pollutive suitable and viable alternative to synthetic fungicides (Joseph et al 2008). The present investigations were undertaken to determine the efficacy of some commonly available plant extracts under north western himalayan areas in controlling wheat PM under *in vitro*, greenhouse and field conditions.

MATERIAL AND METHODS

Leaf extracts of eight commonly available plants i.e., Banna (*Vitex negundo*), Akk (*Calotropis gigantia*), Barhen (*Acorus calamus*), Lantana (*Lantana camara*), Neem (*Azadirachta indica*), Dharek (*Melia azedarach*), Eupatorium (*Eupatorium adenophorum*) and Basooti (*Justicia adhatoda*) were evaluated with recommended fungicide propiconazole and control. The fresh leaves of each plant (4kg each) were crushed properly and mixed in 10 litres each of water and cow urine. The mixture was incubated at ambient temperature (18-20°C) in rust-proof containers and the leaves were sieved out after 15 days of fermentation except in case of neem, where the leaves (10 kg) were put in equal quantity of water (10 litres) and were boiled till the content was reduced to half. Thereafter, 4 litres cow urine was added to the boiled decoction. The decoctions so obtained were was considered as 100 per cent stock solution out of which dilutions of 5, 10, 15, 20 per cent concentrations were used.

***In vitro* evaluation of plant extracts:** Conidiospore germination technique was followed using 5, 10, 15 and 20 per cent concentration of PEs to determine their efficacy to inhibit the germination. PEs were prepared by adding known quantity of stock solution in sterilized distilled water. The fresh and viable conidia were suspended on dry and clean cavity slides having 0.05-0.1ml of each PE at different concentrations. The slides were placed in petri plates lined with filter papers moistened with sterile distilled water and were incubated in BOD incubator at 25±1°C. Observations were recorded on spore germination after 24, 48 and 72 h using research microscope at 40x. The slides with conidia in sterile distilled water served as control. The percent conidial germination and inhibition was calculated (Vincent (1947):

$$\text{Per cent inhibition (PI) of spore germination} = \frac{C-T}{C} \times 100$$

Where, PI - Per cent inhibition; C - Germination of conidia in control; T - Germination of conidia in treatment.

***In vivo* evaluation of Plant Extracts**

Greenhouse: Seedlings of a susceptible wheat var. HPW 155 were raised in 10cm diameter pots filled with garden soil and FYM in the ratio of 10:1. The plant extracts were sprayed @ 15 and 20 per cent conc. as pre (preventive) and post (curative) inoculation applications on 10-day old seedlings (at 1-2 leaf stage). Foliar spray of fungicide propiconazole 25% EC @ 0.1% and water were included as recommended and no spray check, respectively for the comparison. The plants were inoculated by locally available isolate of the *Bgt* by dusting fresh and viable conidia 24h before and after spraying of plant extracts. Each treatment was replicated thrice. The data were recorded on per cent disease severity (Mayee and Datar 1986) 10 days after spraying and per cent disease control was calculated.

Field study: The efficacy of different plant extracts was evaluated under field conditions in the experimental fields of CSK Himachal Pradesh Agricultural University, Palampur during the cropping season 2018-19. The susceptible variety HPW 155 was sown in (5m^2) plots, following recommended agronomical practices (http://www.hillagric.ac.in/extension/dee/pdf_files/Rabi_28-8-09.PDF) under irrigated conditions in randomized block design with three replications. The plant extracts, found effective under *in vitro* and greenhouse conditions, were selected for the evaluation at effective dose (15%) and propiconazole 25% EC @ 0.1% and water sprayed plots were included as recommended checks. The foliar sprays were initiated with the appearance of disease and were repeated fifteen days thereafter. The data were recorded for terminal disease reaction on 50 randomly selected plants per plot using 0-9 scale (Saari and Prescott 1975) and was used to work out per cent disease index given by McKinney (1923):

$$\text{Per cent disease index (PDI)} = \frac{\text{Sum of all disease ratings}}{\text{Total no. of plants observed} \times \text{maximum disease score}} \times 100$$

The per cent disease control (%) was calculated by using following formula:

$$\text{Disease control \%} = \frac{PDI_C - PDI_T}{PDIc} \times 100$$

Where, PDIc = PDI in control plot; PDI_T = PDI in treated plot

The data were also recorded on plot yield after harvesting of the crop and were presented as yield q/ha and per cent increase in yield.

Cost benefit ratio (C:B) was calculated (Reddy et al 2004):

Cost benefit ratio (C:B) = total profit (Rs/ha) / total expenditure (Rs/ha)

Data analysis: The data from *in vitro* and greenhouse experiments were analyzed using a completely randomized design (CRD), while field data followed randomized block design (RBD) and factorial randomized block design (FRBD). After angular transformation, the data were analyzed with CPCS 1 and OP Stat version 4.0.5 software (R Core Team 2021). Duncan's Multiple Range Test in R-Studio version 4.0.5 software (R Core Team 2021) was used to compare means among concentrations, treatments, and their interactions for conidiospore germination and disease severity.

RESULTS AND DISCUSSION

In vitro* evaluation of plant extracts against *Blumeria graminis* f. sp. *tritici: The conidial germination inhibition increased with the enhanced plant extract (PE) concentration. All treatments resulted in significantly less conidial germination ranging between 9.88-44.74 per cent (Table 1) as compare to the control i.e. germination in sterile distilled water (60.20%). However, it was more as compared with the germination in the recommended fungicide check i.e. propiconazole @ 0.1% (9.88%) with corresponding conidial germination inhibition of 96.02 per cent. PEs showed significantly less mean conidiospore germination at 20 percent concentration (30.50%) than at 5, 10, 15 per cent concentration. The minimum mean spore germination of 23.43 per cent was in *A. indica* followed by *C. gigantia* and *J. adhatoda*. The highest conidial germination was in *Eupatorium adenophorum* (44.74%) at all the concentrations followed by *Vitex negundo* (43.93%). Concentration and treatment interaction was non-significant at 24 hours whereas, it was significant at 48 and 72 hours. As has been observed in present studies, Ashlesha and Paul (2017) examined *in vitro* antifungal activity of five plant extracts *viz., Ranunculus muricatus* L., *Vitex negundo* L., *Murraya koenigii* (L.) Sprengel, *Melia azedarach* L. and *Eupatorium* L. against seven fungal phytopathogens namely *Sclerotium rolfsii*, *Fusarium solani* f. sp. *pisi*, *F. oxysporum* f.sp. *pisi*, *Sclerotinia sclerotiorum*, *Rhizoctonia solani*, *Phytophthora nicotianae* var *nicotianae* and *Colletotrichum capsici*. Aqueous extract of *V. negundo* showed significant antifungal activity against *S. rolfsii* (91.3%) and *C. capsici*. which was followed by *M. azedarach* against *P. nicotianae* var *nicotianae* (92.8%) and *Eupatorium* against *P. nicotianae* var *nicotianae* (93.5%) and *C. capsici* (93.2%). Khunt et al (2017) reported that six phyto-extracts showed >50% spore germination inhibition of cumin PM (*Erysiphe polygoni*) at various concentrations after 24, 48 and 72 hours. Significantly, the highest spore germination inhibition (83.05%) was recorded in neem extracts followed by garlic (81.21%) after 72 h at 10 per cent concentration. Meena et al (2019) observed that under *in vitro* conditions neem leaf extract was the most effective against PM of black gram (*Erysiphe polygoni*) with 43.01 to 62.14 per cent spore germination inhibition at 2 and 15 per cent concentration, respectively. Riya (2023) observed that only *Eucalyptus hybrida* was effective in inhibiting the growth of *Xanthomonas campestris* and maximum diametric inhibition zone was 1.85 mm at 20 per cent concentration.

Evaluation of plant extracts in greenhouse: All the treatments resulted in significantly less disease severity as compared with the water spray check (53.74%) (Table 2). Propiconazole 25% EC @ 0.1% resulted in the least disease severity and the highest disease control both in the preventive and curative treatments. Among all plant extracts, *A. indica* and *C. gigantia* were highly effective both as the preventive and curative treatments and as preventive treatments at 15 and 20 per cent concentrations, and resulted in the least disease severity and was followed by *J. adhatoda* and *A. calamus*. In curative treatment, the mean disease severity of 19.49 and 15.92, 20.49 and 16.59 per cent were recorded in *A. indica* and *C. gigantia* with corresponding disease control of 82.05 and 88.21 and 81.03 and 87.18 per cent, respectively at 15 and 20 per concentrations. It was followed by *J. adhatoda* and *A. calamus*. Concentration and treatment interaction was non-significant for both the preventive and curative treatment Rettinassababady et al (2000) also observed that neem seed kernel extracts (5%)

Table 1. Efficacy of urine-basedplant extracts (PEs) on conidiospore germination of *Blumeria graminis* f. sp. *tritici*

Treatment	Conidial germination (%)					Conidial inhibition (%)				
	5%	10%	15%	20%	Mean	5%	10%	15%	20%	Mean
Vitex negundo	51.33 (45.75)*	50.33 (45.17)	47.00 (43.26)	44.00 (41.54)	48.16[h] (43.93)	31.85	33.18	37.61	41.59	36.06
Calotropis gigantia	23.00 (28.64)	21.66 (27.72)	20.00 (26.54)	16.67 (24.08)	20.33[c] (26.75)	69.47	71.24	73.45	77.88	73.01
Acorus calamus	33.00 (35.05)	32.66 (34.84)	31.00 (33.82)	28.66 (32.34)	31.33[e] (34.01)	56.19	56.64	58.84	61.94	58.40
Lantana camara	35.00 (36.26)	34.00 (35.65)	32.66 (34.84)	29.33 (32.78)	32.75[f] (34.88)	53.54	54.87	56.64	61.06	56.53
Azadirachta indica	18.66 (25.58)	18.00 (25.09)	14.33 (22.24)	12.66 (20.83)	15.91[b] (23.43)	75.22	76.11	80.97	83.18	78.87
Melia azedarach	38.33 (38.24)	38.00 (38.04)	36.33 (37.05)	33.33 (35.25)	36.50[g] (37.14)	49.11	49.55	51.77	55.75	51.55
Eupatorium adenophorum	51.33 (45.75)	52.33 (46.32)	50.00 (44.98)	44.67 (41.92)	49.58[i] (44.74)	31.85	30.53	33.62	40.70	34.18
Justicia adhatoda	26.33 (30.86)	22.00 (27.95)	20.66 (27.02)	17.33 (24.59)	21.58[d] (27.60)	65.04	70.79	72.57	76.99	71.35
Propiconazole 25% EC (Tilt) @ 0.1%	3.00 (9.88)	3.00 (9.88)	3.00 (9.88)	3.00 (9.88)	3.00[a] (9.88)	96.02	96.02	96.02	96.02	96.02
Control	75.33 (60.20)	75.33 (60.20)	75.33 (60.20)	75.33 (60.20)	75.33[j] (60.20)	-	-	-	-	
	35.53[a]	34.73[c]	33.03[b]	30.50[a]						
LSD (p=0.05)	Concentration=0.73, Treatment=1.15, Concentration X Treatment=2.30									

*Figures in parentheses are arc sine transformed values were highly effective in suppressing *Erysiphe polygoni* in black gram under pot culture experiment. Extracts of ginger, curcuma and giant knot weed (*Reynoutria sachalinensis*) leaves were highly effective for wheat PM management (Vechet and Sera 2015). Dubey (2016) tested aqueous extracts of three plants i.e. *Eucalyptus camaldulensis*, *Allium sativum* and *Azadirachta indica* against *Phytophthora infestans* causing late blight of tomato under net house condition. All the treatments significantly reduced the severity of late blight over untreated control. The most effective treatment was clove extract of *A. sativum* followed by *E. camaldulensis* and *A. indica*. Mishra et al (2017) observed that neem leaf extract resulted in significantly less disease incidence (37.20%) of peas PM (*Erysiphe pisi*) as compared with water sprayed check (51.33). Bankatdas (2019) reported that the foliar spray of azadirachtin (10%) under pot culture conditions resulted in less incidence (34.12%) and intensity (18.29%) of coriander PM followed by turmeric extract (10%) and ginger extract (10%).

Evaluation in field: Field trial was conducted to assess the efficacy of 6 promising PEs @ 15 per cent concentration along with propiconazole 25EC @ 0.1% and water sprayed plots as recommended and no spray checks, respectively. All the test PEs resulted in significantly less disease severity (Table 3) as compared with check plots (58.65%) and increased seed yield compared to untreated check (24.77 q/ha). However, recommended fungicide propiconazole 25% EC @ 0.1% was the most effective with maximum disease control (88.33%) and higher yield (38.50 q/ha). Among the plant extracts, the least percent disease index (PDI) of 19.05 per cent with corresponding disease control of 85.28 per cent, was with PEs of *C. gigantia* and was followed by *J. adhatoda* and *A. indica* with corresponding disease control of 81.73 and 74.11 per cent, respectively. Among the PEs, the highest grain yield of 34.63 q/ha with an increase of 9.86 q/ha i.e. 39.82 per cent increase over check was recorded with *C. gigantia* and was at par with the yield with *J. adhatoda* (32.93 q/ha) and *A. indica* (32.20 q/ha) with 8.16 (32.96%) and 7.43 q/ha (30.00%) increase in yield over the check. The highest 1000 grain weight i.e. 49.33 g was with *J. adhatoda* followed by *C. gigantia* and *A. indica*. The highest net profit of Rs.14649 per ha were recorded in plots sprayed with *C. gigantia* followed by *J. adhatoda* indicating that *C. gigantia* was the most effective in controlling wheat powdery mildew.

Table 2. Efficacy of cow urine based different plant extracts on terminal disease severity of wheat powdery mildew in potted seedlings of var. HPW 155 in greenhouse

Treatment	Disease severity and disease control (%) over check under											
	Preventive treatment at						Curative treatment at					
	15%	20%	Mean	15%	20%	Mean	15%	20%	Mean	15%	20%	Mean
	Disease severity (%)	Disease severity (%)		Disease control (%)	Disease control (%)		Disease severity (%)	Disease severity (%)		Disease control (%)	Disease control (%)	
Vitex negundo	24.33 (29.54)*	21.33 (27.50)	22.83^{d} (28.52)	62.56	67.18	64.87	28.67 (32.35)	25.67 (30.42)	27.16^{f} (31.38)	55.90	60.51	58.21
Calotropis gigantia	10.67 (19.04)	6.67 (14.95)	8.66^{a} (16.99)	83.59	89.74	86.67	12.33 (20.49)	8.33 (16.59)	10.33^{bc} (18.54)	81.03	87.18	84.11
Acorus calamus	16.67 (24.03)	13.33 (21.36)	15.00^{b} (22.70)	74.36	79.49	76.93	15.00 (22.59)	13.33 (21.14)	14.16^{cd} (21.86)	76.92	79.49	78.21
Lantana camara	26.00 (30.63)	23.00 (28.64)	24.50^{d} (29.64)	60.00	64.62	62.31	18.00 (25.07)	16.67 (24.07)	17.33^{d} (24.57)	72.31	74.36	73.34
Azadirachta indica	9.00 (17.43)	7.33 (15.65)	8.16^{a} (16.54)	86.15	88.72	87.44	11.67 (19.49)	7.67 (15.92)	9.66^{b} (17.71)	82.05	88.21	85.13
Melia azedarach	20.67 (27.02)	15.00 (22.77)	17.83^{c} (24.89)	68.21	76.92	72.57	21.67 (27.70)	21.00 (27.21)	21.33^{e} (27.46)	66.67	67.69	67.18
Eupatorium adenophorum	32.67 (34.83)	28.33 (32.14)	30.50^{e} (33.49)	49.74	56.41	53.08	38.33 (38.24)	35.67 (36.65)	37.00^{g} (37.44)	41.03	45.13	43.08
Justicia adhatoda	16.33 (23.81)	14.67 (22.48)	15.50^{bc} (23.15)	74.87	77.44	76.16	12.67 (20.80)	9.00 (17.20)	10.83^{bc} (19.00)	80.51	86.15	83.33
Propiconazole 25% EC (Tilt) @ 0.1%	6.00 (14.14)	6.00 (14.14)	6.00^{a} (14.14)	90.77	90.77	90.77	5.67 (13.75)	5.67 (13.75)	5.66^{a} (13.75)	91.28	91.28	91.28
Control	65.00 (53.74)	65.00 (53.74)	65.00^{f} (53.74)				65.00 (53.74)	65.00 (53.74)	65.00^{h} (53.74)			
LSD (p=0.05)	Concentration=1.10, Treatment=2.47, Concentration X Treatment=NS						Concentration=1.71, Treatment=3.84, Concentration X Treatment=NS					

*Figures in parentheses are arc sine transformed value

Table 3. Efficacy of cow urine based different plant extracts @ 15 per cent as two foliar sprays against wheat powdery mildew var. HPW 155 under field conditions

Treatments	PDI (%)	Disease control (%)	Mean yield (q/ha)	Increase over check (q/ha)	Yield increase (%)	1000 seed wt (g)	Total profit (Rs/ha)	Expenditure (Rs/ha)	Net profit (Rs/ha)	C:B
Acorus calamus	24.44 (29.61)	66.50	30.77	6.00	24.21	47.45	11034	3500	7534	3.15
Lantana camara	32.59 (34.79)	55.33	28.40	3.63	14.65	47.30	6679	3500	3179	1.91
Azadirachta indica	18.89 (25.74)	74.11	32.20	7.43	30.00	48.20	13671	3500	10171	3.91
Melia azedarach	40.37 (39.43)	44.67	28.80	4.03	16.27	45.35	7415	3500	3915	2.12
Calotropis gigantia	10.74 (19.05)	85.28	34.63	9.86	39.82	48.64	18149	3500	14649	5.19
Justicia adhatoda	13.33 (21.39)	81.73	32.93	8.16	32.96	49.33	15021	3500	11521	4.29
Propiconazole 25% EC (Tilt) @ 0.1%	8.52 (16.68)	88.33	38.50	13.73	55.43	49.50	25263	4000	21263	6.32
Control	72.96 (58.65)		24.77			45.61				
CD (p=0.05)	3.22		2.57			1.01				

*Figures in parentheses are arc sine transformed value
Labour cost= Rs 260/man/day (5 man/ha), MSP of wheat= Rs 1840,
Rate of Tilt (Propiconazole 25EC) = Rs 1400, Rate of plant extracts= Rs 30/lt

Dinesh et al (2015) also reported that azadirachtin and NSKE at 5 per cent conc. were the most effective in controlling sunflower PM with the least disease index of 25.78 and 27.56 per cent, respectively in contrast to 83.33 per cent disease index in control. Yadav et al (2017) reported that neem leaf extract @ 10% resulted in the least PM intensity (21.55%) of green gram followed by garlic clove extract @ 10% (22.87%). Similarly, Kubde et al (2020) reported less powdery mildew incidence in chilli sprayed with garlic (37.14%) followed by holy basil, turmeric, NSKE neem, onion and mehndi compared with the no spray check (56.21%).

The ethanolic extract showed the presence of many biologically active molecules such as flavonoids, alkaloids, triterpenoids, steroids, saponins, phenols and glycosides in *Calotropis gigantea*, which had strong antimicrobial activity and serve as plant defense mechanism against fungal plant pathogens (Saratha et al 2010).The phytochemical analysis of leaves extracts of *Justicia adhatoda* revealed the presence of various components such as alkaloids, anthraquinones, flavonoids, saponins, phytosterols, triterpenoids and poly-phenols (Jayapriya and Shoba 2015) whereas, *A. indica* has been reported to contain 18 active principles including terpenoids, azadirachtin, azadiradione, epoxy-azadiradione, nimbin, solannin, 6-diacethyl-nimbin amongst others. The inhibitory effect of *A. indica* may be due to the presence of antimicrobial compounds especially azadirachtin (Enyiukwu et al 2014).

CONCLUSION

Among various PEs, *A. indica*, *C. gigantia* and *J. adhatoda* were highly effective under *in vitro*, greenhouse and field conditions in reducing the disease severity of wheat powdery mildew and increase yield. Hence, these may be used as alternative to fungicides for the management of PM. Botanical pesticides integrated with other plant disease management practices i.e. varieties with low level of resistance can reduce human health risks and pollution of environment, water and soil. Hence, these will improve export earnings through reducing chemical residue levels on export commodities. These may be the potential candidates for PM management under organic and natural farming and the weed flora being used to prepare extracts at commercial level may be effectively managed and utilized.

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In vitro Interactions of *Bacillus thuringiensis* with Biorationals and Synthetic Insecticides

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Abstract: Managing crop pests using microorganism is one of the key component and eco-friendly alternative to reduce chemical inputs in integrated farming systems. Biorationals and chemical pesticides can exert either antagonistic or synergistic effects on the efficacy of entomopathogens potentially impacting natural epizootic outbreaks. The present study was therefore undertaken to evaluate the in vitro compatibility between *Bacillus thuringiensis* with biorationals and synthetic insecticides. The findings revealed that *B. thuringiensis* MTCC 9025 recorded minimum growth percent reduction over control with *Beauveria bassiana* PCP-6 (5.33%) and *B. bassiana* MTCC 6097 (12.76%) and were highly compatible. However, *B. thuringiensis* MTCC 8481 recorded maximum growth percent reduction and was least compatible. All *B. thuringiensis* isolates were compatible with azadirachtin 5% w/w (@0.2ml/l and @0.4ml/l) and synthetic insecticide Chlorantraniliprole 18.5% SC (@0.2ml/l and @0.4ml/l). However, all *B. thuringiensis* isolates were incompatible with Emamectin benzoate 5% SG and exhibited maximum growth percent reduction over control. The results indicated that *B. thuringiensis* isolates could be successfully integrated into Integrated Pest Management strategies with *Beauveria bassiana* isolates, azadirachtin 5 % w/w and chlorantraniliprole 18.5% SC.

Keywords: Azadirachtin, *Bacillus thuringiensis, Beauveria bassiana,* Chlorantraniliprole, Emamectin benzoate, Compatibility

Microbial pest management is an ecofriendly method to reduce chemical inputs in agricultural systems. Indiscriminate and excessive use of chemical insecticides has negative effects and there is need to reduce their use and introduce various ecofriendly biorationals. Various biocontrol agents *viz*. entompathogens, botanicals, natural enemies are exploited for the management of crop pests, may have antagonistic or synergistic effects on the potentiality of entomopathogens and may influence natural epizootics (Garcia-Riano et al 2022). Entomopathogens like *B. thuringiensis, Metarhizium anisopliae, M. rileyi, B. bassiana* are mainly exploited for management of insect pest (Matcha et al 2021). *B. thuringiensis* is important soil bacterium that produces a variety of bioactive compounds, including insecticidal protein and thuringinsin (Savini and Fazii 2016). The entomopathogenic fungus, *B. bassiana* naturally exists in the soil and has good epizootic potential, infecting the insect by adhesion to their cuticle by adhesion proteins. Entomopathogenic fungi act as immunosuppressive compounds, leading to mycosis of crop insects (Shashikala et al 2023). Botanicals offer a safer alternative, posing minimal risk to humans and allowing easy combination with various other biological agents. Neem based formulations are environmentally safe and disrupts the insect growth and development and prevents insect resistance development (Bharti et al 2023). Compatibility studies between various bioagents are important as incompatible biocontrol agents may negatively affect the efficacy of integrated pest management programme (Sarkhandia et al 2023). Therefore, it is important to determine the interactions of *B. thuringiensis* with other biorationals to maximize their combined efficacy.

MATERIAL AND METHODS

Five *Bacillus thuringiensis* isolates *viz. B. thuringiensis* MTCC 9025, *B. thuringiensis* MTCC 868, *B. thuringiensis* MTCC 8481, *B. thuringiensis* MD4, *B. thuringiensis* (commercial formulation) and two *Beauveria bassiana* isolates *B. bassiana* MTCC 6097 and *B. bassiana* PCP-6 along with azadirachtin 5% w/w, emamectin benzoate 5% SG and chlorantraniliprole 18.5% SC were selected for compatibility studies. Three *B. thuringiensis isolates viz. B. thuringiensis* MTCC 9025, *B. thuringiensis* MTCC 868, *B. thuringiensis* MTCC 8481 and one *B. bassiana* MTCC 6097 procured from Institute of Microbial Technology (IMTECH), Chandigarh were grown on their respective growth media and maintained at 4°C till further use.

Five *Bacillus thuringiensis* were studied for compatibility with two isolates of *B. bassiana viz. B. bassiana* MTCC 6097 and *B. bassiana* PCP-6 according to dual culture technique by Udayababu and Zacharia (2021). In vitro compatibility of *B. thuringiensis* with the neem-based formulation (azadirachtin 5% w/w) and synthetic insecticides (emamectin benzoate 5% SG and chlorantraniliprole 18.5% SC) were also studied. Neem based formulation (azadirachtin 5% w/w) (@ 0.2 and @ 0.4ml/l)), emamectin benzoate 5% SG and chlorantraniliprole 18.5% SC (0.2 and 0.4ml/l respectively), were added individually to the sterilized Luria Bertani agar supplemented with *B. thuringiensis* and this supplemented media was poured aseptically into petriplates and allowed to solidify according to methodology of Dev et al (2021).These petriplates were incubated @32±2°C for 24-48h and compared with control plates (without any supplementation of azadirachtin in growth media) and (without any supplementation of individual insecticides) in growth media. There were four replications per treatment.

The growth of the *B. thuringiensis* was evaluated by determining whether they exhibited inhibitory or supportive interactions. The effect of the bacterial isolates on mycelial development was calculated to assess their influence.

$$\%\ \text{growth inhibition} = \frac{\text{Control} - \text{Treatment}}{\text{Control}} \times 100$$

Control = radial growth of *Beauveria bassiana* in control plate
Treatment = radial growth of *Beauveria bassiana* in co-cultivation with *B. thuringiensis* isolates

The viable count of *B. thuringiensis* isolates (CFU/ml) were recorded in control and compared with viable count of *B. thuringiensis* on media supplemented with azadirachtin or insecticide individually according to methodology of Sarkhandia et al (2023) with some little modifications. The Inhibitory effect of biopesticides, percent growth reduction over control was recorded and was classified according to following scale (Derakhshan Shadmehri et al 2016),

RESULTS AND DISCUSSION

Maximum radial growth (8.42±0.15) and the minimum growth percentage reduction over control (5.33%) were observed in *B. bassiana* PCP-6 when inoculated and incubated on growth media supplemented with *B. thuringiensis* MTCC 9025. Conversely, the minimum radial growth (3.64±0.24) and the maximum growth percentage reduction (59.02%) were in *B. bassiana* PCP-6 supplemented with *B. thuringiensis* MTCC 8481 (Table 1). In co-cultivation studies of *B. thuringiensis* with *B. bassiana* MTCC 6097, maximum radial growth (7.45±0.11) and the minimum growth percentage reduction over control (12.76%) were in *B. bassiana* MTCC 6097 supplemented with *B. thuringiensis* MTCC 9025 and minimum radial growth (4.14±0.09) and the maximum growth percentage reduction (51.50%) were in *B. bassiana* MTCC 6097 supplemented with *B. thuringiensis* MTCC 8481. Compatibility studies of *B. thuringiensis* with *B. bassiana* recorded variation in compatibility. However, least compatibility of *Beauveria bassiana* was recorded with *B. thuringiensis* MTCC 8481.

Luria Bertani agar media supplemented individually with azadirachtin 5% w/w (@0.2ml/l and 0.4ml/l) recorded maximum colony count (9.6×10^6cfu/ml) and (9.1×10^6cfu/ml) and minimum growth percentage reduction compared to the control (5.88% and 10.78%) respectively, in *B. thuringiensis* MTCC 9025. In contrast, the minimum colony count (6.4×10^6cfu/ml) and (6.2×10^6cfu/ml) and maximum growth percentage reduction over control (26.43% and 28.73%) respectively, were recorded with *B. thuringiensis* MTCC 868. All *B. thuringiensis* isolates were moderate to high compatible with azadirachtin 5% w/w (Table 2).

Compatibility studies of *B. thuringiensis* with chemical insecticide chlorantraniliprole 18.5% SC (@0.2 and @0.4ml /l) recorded maximum colony count (8.1×10^6cfu/ml) and (7.9×10^6cfu/ml) and least percent reduction over control (20.58% and 22.54%) respectively in *B. thuringiensis* MTCC 9025 and was moderate compatible with both doses of chlorantraniliprole 18.5% SC, whereas minimum colony count (6.2×10^6 and 5.9×10^6cfu/ml) and maximum percent reduction over control (28.73% and 32.18%), respectively in *B. thuringiensis* MTCC 868 and was moderate compatible (Table 3). However, emamectin benzoate 5% SG recorded

Table 1. Co-cultivation of *B. thuringiensis* with *B. bassiana* (Mean± S.E.)

Treatments	Radial growth of *B. bassiana* PCP-6 (cm)				Radial growth of *B. bassiana* MTCC 6097 (cm)			
	Control*	**Media supplemented with *B. thuringiensis*	Reduction over control (%)	CI	Control*	**Media supplemented with *B. thuringiensis*	Reduction over control (%)	CI
B. thuringiensis MTCC 9025	8.9±0.02	8.42±0.15	5.33	HC	8.55±0.10	7.45±0.11	12.76	HC
B. thuringiensis MTCC 868	8.9±0.02	6.59±0.17	25.91	MC	8.55±0.10	6.94±0.09	18.79	HC
B. thuringiensis MTCC 8481	8.9±0.02	3.64±0.24	59.02	LC	8.55±0.10	4.14±0.09	51.50	LC
B. thuringiensis MD4	8.9±0.02	8.08±0.15	9.17	HC	8.55±0.10	7.07±0.03	17.30	HC
B. thuringiensis (Commercial formulation)	8.9±0.02	6.74±0.10	24.25	MC	8.55±0.10	6.79±0.14	20.56	MC

#Value of mean± standard error (mean± S.E.) of four replicates
* Radial growth of *B. bassiana* on media without *B. thuringiensis* supplementation
** Radial growth of *B. bassiana* on media supplemented with *B. thuringiensis*
CI= Compatibility Index, HC= Highly Compatible, MC= Moderately Compatible, LC= Least Compatible

minimum colony count and maximum growth percent reduction over control (89.65% and 91.95%) in *B. thuringiensis* MTCC 868 and maximum colony count and minimum growth percent reduction over control (83.33 and 87.25%) in *B. thuringiensis* MTCC 9025 and was incompatible at both doses (@ 0.2 and @0.4 ml/l). Among both insecticides chlorantraniliprole 18.5% SC was compatible whereas Emamectin benzoate 5% SG was incompatible with *B. thuringiensis.*

Interactive studies of *B. thuringiensis* with *Beauveria bassiana* recorded variation in compatibility. An interactive study of *B. thuringiensis* with azadirachtin 5% w/w was safe and compatible with all *B. thuringiensis*. Among both insecticides, emamectin benzoate reduced viable counts of *Bacillus* drastically and was incompatible, whereas, chlorantraniliprole was compatible and could be used in integrated insect management programme. In vitro compatibility studies between biocontrol bacteria and entomopathogenic fungal strains and growth inhibition of entomopathogenic fungus upto 25% by entomopathogenic bacterial strains was recorded by Sicuia et al (2014). The variation in compatibility in different isolates may be due to precipitation compound observed in the area of fungal growth inhibition. These aspects were observed only in co-cultivation of lectin producing fungi with certain bacterial isolates. The activity of *B. thuringiensis* depends on its insecticidal toxins and various other virulence factors that contribute to insect mortality. *B. thuringiensis* carries various transposons, which contribute to the significant genetic variability of its toxin genes and consequently, the diversity of the toxins it produces. This genetic variability accounts for the wide range of *B. thuringiensis* strains. Variation in

Table 2. Interactions between *B. thuringiensis* and azadirachtin 5% w/w

Treatments	*B. thuringiensis* viable count (CFU/mL) supplemented with azadirachtin 5% w/w						
	Control*	0.2 ml/l			0.4 ml/l		
		Colony count	Reduction over control (%)	CI	Colony count	Reduction over control (%)	CI
B. thuringiensis MTCC 9025	1.02×10^7	9.6×10^6	5.88	HC	9.1×10^6	10.78	HC
B. thuringiensis MTCC868	8.7×10^6	6.4×10^6	26.43	MC	6.2×10^6	28.73	MC
B. thuringiensis MTCC 8481	8.5×10^6	6.7×10^6	21.17	MC	6.5×10^6	23.52	MC
B. thuringiensis MD4	9.8×10^6	8.9×10^6	9.18	HC	8.6×10^6	12.24	HC
B. thuringiensis (Commercial formulation)	9.2×10^6	7.7×10^6	16.30	HC	7.2×10^6	21.73	MC

* Viable count of *B. thuringiensis* without any supplementation
CI= Compatibility Index, HC= Highly Compatible, MC= Moderately Compatible

Table 3. Interactions between *B. thuringiensis* and synthetic insecticides

Treatments	Control*	Viable count of *B. thuringiensis* (CFU/ml) supplemented with											
		Chlorantraniliprole 18.5% SC						Emamectin benzoate 5% SG					
		0.2 ml/l			0.4 ml/l			0.2 ml/l			0.4 ml/l		
		Colony count	Reduction over control (%)	CI	Colony count	Reduction over control (%)	CI	Colony count	Reduction over control (%)	CI	Colony count	Reduction over control (%)	CI
B. thuringiensis MTCC 9025	1.02×10^7	8.1×10^6	20.58	MC	7.9×10^6	22.54	MC	1.7×10^6	83.33	IC	1.3×10^6	87.25	IC
B. thuringiensis MTCC 868	8.7×10^6	6.2×10^6	28.73	MC	5.9×10^6	32.18	MC	9×10^5	89.65	IC	7×10^5	91.95	IC
B. thuringiensis MTCC 8481	8.5×10^6	6.5×10^6	23.52	MC	6.2×10^6	27.05	MC	1.0×10^6	88.23	IC	1.0×10^6	88.23	IC
B. thuringiensis MD4	9.8×10^6	7.6×10^6	22.44	MC	7.4×10^6	24.48	MC	1.3×10^6	86.73	IC	1.1×10^6	88.77	IC
B. thuringiensis (Commercial formulation)	9.2×10^6	7.0×10^6	23.91	MC	6.8×10^6	26.08	MC	1.1×10^6	88.04	IC	9×10^5	90.21	IC

* Viable count of *B. thuringiensis* without any supplementation
CI= Compatibility Index, MC= Moderately Compatible, IC= Incompatible

compatibility of *B. thuringiensis* strains may be due to difference in their insecticidal toxins or diversity of toxins secreted. Compatibility studies in vitro between chemical insecticides and entomopathogenic bacteria have strong evidence in favour of the utility of that combination under field conditions (Pelizza et al 2014).The variation in compatibility study of *B. thuringiensis* may be attributed to differences in microbial growth parameters and chemistry of insecticides used (Saheb et al 2021).The combination of *B. thuringiensis* with biorationals and insecticides are better practice agents to control pest. *B. thuringiensis* influenced antagonistic activity to the azadirachtin, entomopathogenic fungi and insecticides. Paunikar and Kulkarni (2020) reported that azadirachtin is compatible with all entompathogens, and there is possibilities of their combinational treatment under IPM against agriculturally importance pests.

CONCLUSION

B. thuringiensis was compatible with *B. bassiana*, azadirachtin and they could be integrated as component in IPM programme. The insecticide chlorantraniliprole 18.5% SC was better option than emamectin benzoate 5% SG. The synergistic effect of beneficial microorganisms, such as *B. thuringiensis* and entomopathogenic fungi and azadirachtin may facilitate integrated treatments to manage pest infestations simultaneously.

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Exploring the Potential of Oyster Mushroom Cultivation as Remunerative Agri-Enterprise in Punjab

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***Abstract*:** Mushroom cultivation is a remunerative activity that has potential for economic upliftment and empowerment of farmers. While button mushroom cultivation is already established among many farmers in Punjab, oyster mushroom cultivation has not gained as much popularity in the region despite its high nutritive value. In order to evaluate the production and economic efficacy of oyster mushroom cultivation, on-farm trials with 30 farmers were conducted in District Sangrur, Punjab under Farmer FIRST Project. Farmers were provided with spawn and polythene bags for mushroom production, and data were collected on production parameters, yield, economic efficacy, and prospects of the farmers. Results from the trials showed that the average time for the first harvest of produce was 40.1 days (min 34, max 47), with an average yield of 66.2 kg of mushrooms per 100 kg of dry substrate used. So, farmers are getting produce within the 1-1.5 months of the enterprise start. The cost of producing mushrooms from a 5kg compost bag was Rs. 56 while yielding the net profit of Rs. 208 per bag. Furthermore, 70 percent of the surveyed farmers expressed interest in continuing oyster mushroom cultivation, with 62 percent of them showed interest to increase the scale of production. The ease of cultivation, availability of raw materials, and good taste of the oyster mushroom were expressed as favourable factors for adoption. Overall, these results suggest that oyster mushroom cultivation is an easy and profitable agricultural practice and a viable occupation for farmers with minimal resources. However, market feasibility for large-scale production will need to be considered and developed through processing and marketing facilities.

***Keywords*:** Dhingri, Enterprise, Mushroom, Oyster

The state of Punjab, located in Northern India, is known for its vibrant agricultural sector, with a primary focus on staple crops such as wheat and rice with 35.26 and 31.44 lakh hectare area under these crops, respectively. However, the traditional agricultural practices in Punjab face numerous challenges, including decreased profit margins, depleted soil fertility, and water scarcity. Moreover, majority of the farmers (66.78%) in Punjab have landholding size upto four hectares only (GOP 2022). In order to address these challenges, it is crucial to identify and promote remunerative agri-enterprises as subsidiary occupation, that can supplement the income of farmers and contribute to sustainable agricultural development.

One such promising alternative is mushroom cultivation. Punjab produced 19.75 thousand metric tonnes of mushroom which account for 6.93 percent of country's total production in the year 2021-22 (Anonymous 2023). Among the various mushroom types, mushroom industry in the state as well as whole country is dominated by the white button mushroom (Sharma et al 2017). Various processes in button mushroom cultivation specially compost making is a laborious process, which takes 26-27 days for long method and 18 days in short method of composting. So, complexity limits the scalability of this enterprise. In this context, oyster mushroom cultivation is a good and viable option, which is relatively quite easy to cultivate as compared to button mushroom. Oyster mushroom (*Pleurotus* spp.), which is also called "Dhingri" are highly nutritious and have gained significant popularity in recent years due to their medicinal properties, culinary versatility, and potential for commercial cultivation (Nongthombam et al 2021). Oyster mushroom industry has ben growing rapidly in various Asian countries due to its low production cost and high yielding capacity (Raman et al 2021).

Oyster mushroom has the potential to grow on a wide range of agricultural residues such as wheat straw, paddy straw, sorghum residues and mustard straw etc. The cultivation of oyster mushrooms has several advantages over traditional crops. Firstly, it requires relatively less land and can be practiced in small spaces, making it suitable for marginal and small-scale farmers. Secondly, oyster mushroom cultivation has a shorter cropping cycle, typically ranging from 30 to 45 days, allowing for multiple harvests in a year and faster returns on investment. Further oyster mushroom does not require the compost preparation as in button mushroom cultivation. Additionally, oyster mushrooms have unique flavor, high nutritional value and health benefits (Tolera and Abera 2017)

Several studies have highlighted the economic viability and profitability of oyster mushroom cultivation, citing its potential to generate higher returns as compared to traditional crops. In addition to economic benefits, oyster mushroom cultivation can offer environmental advantages. It promotes the utilization of agricultural residues viz paddy residue, wheat straw, sugarcane bagasse, corn cobs and mustard straw. Moreover, the cultivation process requires minimal water and pesticide usage, making it environmentally sustainable and aligning with the principles of organic farming.

However, despite its potential, oyster mushroom cultivation in Punjab is still at a nascent stage, with limited awareness and adoption among farmers. Therefore, this research paper aims to explore the potential of oyster mushroom cultivation as a remunerative agri-enterprise in Punjab. By examining the field experiments and surveys, we assessed the economic viability, market potential, technical requirements, and policy implications of oyster mushroom cultivation in the context of Punjab. The findings of this study will provide valuable insights for policymakers, agricultural extension services, and farmers, facilitating informed decision-making and promoting sustainable agricultural diversification in Punjab.

MATERIAL AND METHODS

The current study was conducted under the Farmer FIRST Programme (FFP). Farmer FIRST Programme (FFP) was introduced in Punjab in the year 2016-17. Two villages Chatha Nanhera and Tranji Khera in district Sangrur were selected under FFP. Button mushroom cultivation as a subsidiary occupation was introduced in these two adopted villages in the year 2016-17. Button mushroom has been popularized among the farmers in project area.

Further to determine the efficacy and potential of oyster mushroom cultivation, oyster mushroom cultivation has been introduced in collaboration with Director of Mushroom Research, Solan, HP. Training camps were organized to equip farmers with the knowledge regarding production technologies of oyster mushroom. To determine the efficacy of oyster mushroom, 30 on-farm trials were conducted in the project villages. Data regarding time taken for first harvest, yield per dry substrate, average wight of fruit body were collected from the 10 locations. One-way Anova with post-hoc LSD was performed to check the difference between 10 locations on the basis of selected parameters. To determine the economic efficacy of the oyster mushroom cultivation in terms of cost, gross benefits, net benefits and benefit to cost ratio were calculated. To explore the farmers reactions towards oyster mushroom cultivation, they were surveyed regarding prospects of oyster mushroom cultivation and favourable factors were also explored from the cultivators.

RESULTS AND DISCUSSION

The on-farm trails of oyster mushroom cultivation provided the data to explore the potential of cultivation in terms of production and temporal indicators. Table 1 presents the findings of on-farm evaluation trials, providing detailed information on the time taken for first harvest, yield per 100 kg of dry substrate, and average weight of a fruiting body for each of the ten locations. The average values across all locations were calculated to determine the overall performance.

The results of the on-farm evaluation trials indicated variations in the performance of oyster mushroom cultivation across different locations. The time taken for first harvest ranged from 34 to 47 days, with an average of 40.1 days. The yield per 100 kg of dry substrate varied between 61.4 kg and 71.6 kg, with an average yield of 66.19 kg. The average weight of a fruiting body ranged from 11.8 g to 17.3 g, with an average of 14.98 g. These findings highlight the importance of location-specific factors, such as climate, substrate quality, and management practices that influences the growth and yield of oyster mushrooms.

Table 2 presents a comparison of oyster mushroom yield obtained by using different crop residues as the substrate. The study aimed to evaluate the impact of varying straw compositions on the yield of oyster mushrooms. Three

Table 1. On-farm evaluation cultivation trials data for oyster mushroom

Farmers	Time taken for first harvest (d)	Yield (kg/100 kg dry substrate)	Av. wt. of a FB (g)
Location 1	34^{d}	62.5	13.0^{bc}
Location 2	42^{bc}	65.7	17.0^{a}
Location 3	38^{cd}	68.0	16.7^{a}
Location 4	45^{ab}	70.2	15.5^{ab}
Location 5	42^{bc}	61.4	12.4^{bc}
Location 6	37^{d}	61.8	11.8^{c}
Location 7	35^{d}	63.9	15.2^{abc}
Location 8	45^{ab}	67.4	14.9^{abc}
Location 9	47^{a}	69.4	16.0^{ab}
Location 10	36^{d}	71.6	17.3^{a}
Average	40.1	66.19	14.98
CD	4.96	NS	3.65

Level of significance = 5%
Bag size: 5kg
Average of 5 bags; Temperature: $25\pm2^{0}C$; Relative humidity: 80-85%

Table 2. Oyster mushroom yield comparison with different crop straw

Straw	Yield (kg/q)
Wheat (100%)	65.25
Wheat: Paddy (1:1)	52.50
Wheat: Mustard (1:1)	49.80

different types of straws were tested: wheat straw alone, a mixture of wheat and paddy straw in a 1:1 ratio, and a mixture of wheat and mustard straw in a 1:1 ratio. The results showed that 100% wheat straw as the substrate resulted in the highest yield of oyster mushroom, with a recorded yield of 65.25 kg/q. This suggests that wheat straw alone provides most favourable conditions for the growth and development of oyster mushrooms, leading to a higher yield.

In contrast, the yields obtained from the mixtures of wheat and paddy straw in a 1:1 ratio and wheat and mustard straw in a 1:1 ratio were lower. The wheat: paddy mixture yielded 52.50 kg/q, while the wheat: mustard mixture yielded 49.80 kg/q. These findings suggest that the presence of paddy and mustard straw in the substrate may have a slightly negative impact on the growth and yield of oyster mushrooms as compared to using pure wheat straw.

Data in Table 3 evaluate the financial aspects of cultivating oyster mushrooms using a standardized unit of measurement, a 5 kg bag. The table provides information on various economic parameters, including total cost, average yield, gross returns, net returns, and the benefit-to-cost ratio.The total cost per bag of oyster mushroom was recorded to be Rs. 56. This figure includes all the expenses incurred in the cultivation process, such as substrate procurement, labour costs, overhead expenses, and other miscellaneous costs.

The average yield per bag of oyster mushroom was found to be 2.20 kg. Based on the average yield, the gross returns per bag of oyster mushroom amount to Rs. 264. For calculating the net return per bag, the total cost was subtracted from the gross return. In this case, the net returns amount to Rs. 208. The benefit-to-cost ratio was calculated by dividing the net returns by the total cost. In this analysis, the benefit-to-cost ratio was observed to be 3.71. This ratio indicated that for every unit of cost invested, the cultivation of oyster mushrooms yields a benefit that was approximately 3.71 times higher.

Table 4 presents the prospects of oyster mushroom cultivation based on the responses of surveyed farmers. The table displays the percentage of farmers who indicated their intentions for the future of oyster mushroom cultivation.

Data revealed that 43.33% of the farmers expressed their intention to increase their oyster mushroom cultivation efforts. These farmers see potential in expanding their mushroom cultivation activities, likely due to positive experiences, expected or experienced profitability. Another 26.67% of the farmers stated that they plan to maintain their current level of oyster mushroom cultivation. These farmers see their current production at household level as satisfactory and have no immediate plans to increase or decrease their efforts. Factors such as personal preferences, or limitations in resources or capacity may contribute to this decision.On the other hand, 30.00% of the farmers expressed their intention to discontinue oyster mushroom cultivation. These farmers have decided to cease their mushroom cultivation activities, possibly due to challenges they faced, such as time constraints, labor constraints, or other factors that have negatively impacted their experience with oyster mushroom cultivation.

Table 3. Economic analysis of the FLDs on Oyster (Dhingri) mushroom cultivation

Particular	Amount (Rs/5 kg bag)
Total cost (Rs./bag)	56.0
Average yield (kg/bag)	2.20
Gross returns (Rs/bag)	264
Net returns (Rs/bag)	208
Benefit: cost ratio	3.71

Table 4. Prospects of oyster mushroom cultivation

Prospect	% farmer
Increase	13 (43.33%)
Same	8 (26.67%)
Discontinue	9 (30.00%)

Favourable factors for adoption of oyster mushroom cultivation as perceived by the farmers: The cultivators were also asked about the factors responsible for favourable perception towards oyster mushroom cultivation and to determine the scalability of the oyster mushroom cultivation, favourable factors for the adoption were determined through qualitative observations from the farmers. It was found that easy availability of raw material, ease in cultivation and good taste of produce are playing a major role in enhancing the favourableness towards adoption among the farmers.

Farmers recognize the easy availability of raw materials required for oyster mushroom cultivation as the most favourable factors. As for the production of oyster mushroom, farmers require wheat straw (or paddy, mustard straw) and spawn. The straw is often readily available on farms or can be sourced locally, reducing the need for extensive investments or reliance on external inputs. The accessibility of raw materials contributes to the feasibility and cost-effectiveness of oyster mushroom cultivation. Further farmers perceived and experienced the ease in cultivation of oyster mushroom. They narrated that it is only one time process, in which they have to soak the straw, pack the straw and spawn in the polythene bags. After the bag process, these is no major task in the cultivation of oyster mushroom cultivation other than the watering. The cultivators cooked at their home and also distributed the oyster mushroom in their neighbourhood. Most of them found oyster mushroom tasty and want to include in their daily diet.

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Analysis of Mineral Content in Cluster Bean [*Cyamopsis tetragonoloba* (L.) Taub] Genotypes for Improving Nutrition and Enhancing Food Security

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Abstract: Addressing the dual challenges of food security and nutritional adequacy, this study was conducted to analyze the mineral composition of twenty cluster bean genotypes to identify those with the highest nutritional value. The evaluation of genotypes revealed significant variations in essential minerals content, including potassium, phosphorus, sodium, calcium, magnesium, iron, and zinc. The study identified several genotypes with high levels of these essential minerals, including VRCB-10 and KAU Suruchi for potassium (1.95%), IC-39983 for phosphorus (0.20%), IC-39981 for sodium (0.25%) and zinc (52.50 ppm), IC-39980 for calcium (1.60%), GP-14 for magnesium (1.69 %) and GP-12 for iron (503.50 ppm). The results of this study can be used to promote the cultivation of cluster bean genotypes that provide superior nutritional value, thereby contributing to improved food security.

Keywords: Minerals, Cluster bean, Nutrition, Legumes

Underexploited vegetables are rich in protein, vitamin A, vitamin C, potassium, calcium, thiamine, riboflavin, folate, antioxidants and dietary fibre. They are cheap, locally available and locally acceptable, hence an ideal alternative for costly off-season vegetables for maintaining the population healthy and nutritionally secure (Pradeepkumar and Divya 2023). Legumes are dicotyledonous annuals or perennials belonging to Fabaceae family and cultivated throughout the world for their nutritious pods and seeds. In developing countries like India, where much of the population falls under low-income categories, affordable and accessible plant protein sources like legumes are crucial in combating malnutrition. So, consumption of legume vegetable needs to be given attention (Aghora et al 2023).

Cluster bean [*Cyamopsis tetragonoloba* (L.) Taub.] [2n=14] is one of the most important underexploited leguminous vegetable belonging to the family Fabaceae. This drought-tolerant annual crop has high socioeconomic value and is primarily cultivated in arid and semi-arid regions for its tender pods and seed endospermic gum. High adaptation towards erratic rainfall, multiple industrial uses and importance in cropping system for soil enrichment properties, low input requirement, etc. have made guar one of the most significant crops for farmers in arid areas in India (Kumari et al 2020). Cluster beans offer numerous health benefits, being rich in fibre, protein, and essential nutrients. They helpto lower LDL cholesterol, support heart health, and boost haemoglobin levels. Their calcium and phosphorus content strengthens bones, while their low hypoglycemic properties aid in blood sugar control, making them ideal for diabetics. Additionally, they promote foetal development, prevent birth defects, and calm nerves. Rich in vitamins A, B, K, and minerals like calcium, iron, and potassium, cluster beans also act as a natural laxative (Mall and Tripathy 2015).

Research works focused mostly on more popular vegetables like tomato, chilli, watermelon, cucumber, brinjal etc. Minor work has been done on improvement of underutilized vegetables, which form the future vegetables that provide nutritional security to rural people. (Palanisamy et al 2015). Hence, the present investigation was done to analyze the nutrient composition of various cluster bean [*Cyamopsis tetragonoloba* (L.) Taub.] genotypes, with a particular emphasis on their mineral content, aiming to improve nutrition and enhance food security.

MATERIAL AND METHODS

Experimental site: The present study was conducted at the Department of Vegetable Science, College of Agriculture, Vellayani, Thiruvananthapuram of Kerala during 2022- 2024. The experimental plot was situated at a latitude of 8.4° N and a longitude of 76.9° E, at an altitude of 29.00 m above mean sea level. The predominant soil type of the experimental site was red loam belonging to Vellayani series, with a sandy clay loam texture. The region experiences a warm, humid tropical climate.

Treatment details: Seeds of twenty genotypes of cluster bean were collected from state and national institutes, research stations along with the released variety of Kerala Agricultural University (Table 1). Seeds of twenty genotypes of cluster bean were sown under open field conditions in a plot size of 4.50 m^2. Seeds @ 10 to 12 kg ha^{-1} were planted at a spacing of 60 cm x 30 cm. The crop was raised according to the package of practices recommendations (KAU 2016). The experiment was laid out in randomized block design with two replications comprising of twenty treatments of cluster bean.

Mineral Analysis

Potassium (%): The dried pod samples of cluster bean were digested using a diacid (HNO_3: $HClO_4$ in a ratio 9:4) and potassium in the digest was estimated by flame photometry method (Jackson 1973).

Phosphorus (%): The dried pod samples of cluster bean underwent diacid digestion (HNO_3: $HClO_4$ in a 9:4 ratio) and were estimated using the "Vanadomolybdophosphoric acid" yellow colour method (Jackson 1973). Readings were taken using a spectrophotometer at 470 nm.

Sodium (%): The sodium content in cluster bean samples was determined using the Flame Photometer method (Jaiswal 2003)after subjecting the samples to diacid (HNO_3: $HClO_4$ in a ratio 9:4) digestion. Sodium chloride solution was used as a standard.

Calcium (%): Calcium content was estimated using the method described by Hesse (1971). The dried pod samples underwent diacid digestion (HNO_3: $HClO_4$ in a 9:4 ratio) and were assessed using the Versanate titration method.

Table 1. Details of cluster bean genotypes

Source	Genotypes
NBPGR Regional Station, Jodhpur, Rajasthan	IC-39980
	IC-39981
	IC-39983
	IC-39984
	IC-39985
	IC-39986
	IC-11463
RARI Durgapur, Rajasthan	GP-4
	GP-8
	GP-12
	GP-14
	GP-19
	GP-20
ICAR- IIVR Varanasi, Uttar Pradesh	VRCB-10
	VRCB-47
	VRCB-57
	VRCB-87
Rajasthan local	Sikar
ICAR- IARI, New Delhi	Pusa Navbahar
College of Agriculture, Vellayani	KAU Suruchi

Magnesium (%): Magnesium content was determined using the method described by Hesse (1971). The dried pod samples underwent diacid digestion (HNO_3: $HClO_4$ in a 9:4 ratio) and were assessed using the Versanate titration method.

Iron (ppm): The cluster bean samples were digested using a diacid (HNO_3: $HClO_4$ in a ratio 9:4) and analyzed for iron content using Atomic Absorption Spectrophotometer method (Jackson 1973).

Zinc (ppm): The samples of cluster beans underwent digestion using a diacid (HNO_3: $HClO_4$in a 9:4 ratio) and were then analyzed for zinc content using the Atomic Absorption Spectrophotometer method (Jackson 1973).

Statistical analysis: The data was statistically analyzed in randomized block design using KAU GRAPES (Gopinath et al 2021).

RESULTS AND DISCUSSION

Potassium: The potassium content varied significantly among the different genotypes, with levels ranging from 1.00% (GP-4) to 1.95% (VRCB-10 and KAU Suruchi) (Table 1). Akcura et al (2020) also observed significant variation among ten different vegetable cluster bean genotypes for potassium and recorded a range of potassium content from 2.26 to 2.54%.

Phosphorus: Significant differences were observed in phosphorus content among the genotypes, ranging from 0.02% (IC-39981, IC11463, GP12 and VRCB 47) to 0.20% (IC-39983). Chhipa (2011) observed 0.25% phosphorus content in vegetable cluster bean. Akcura et al (2020) recorded phosphorus content ranging from 0.23 to 0.27% among ten different cluster bean genotypes.

Sodium: The genotypes exhibited significant differences for sodium content, ranging from 0.10% (IC-39984, IC-39985, GP-12 and VRCB-10) to 0.25% (IC-39981). On the contrary, Akcura et al (2020) observed sodium content ranging from 3.08 to 6.09% among different cluster bean genotypes.

Calcium: Genotypes showed a significant variation in calcium content, ranging from 0.40% (GP-14, Sikar and KAU Suruchi) to 1.60% (IC-39980). Akcura et al (2020) observed calcium content ranging from 0.68 to 0.89% in different cluster bean genotypes.

Magnesium: There was significant difference among the genotypes for magnesium content, which ranged from 0.53% (IC-39986) to 1.69% (GP-14). GP-14 was statistically on par with GP-4 and VRCB-47 (1.68%). Akcura et al (2020) recorded magnesium content ranging from 0.53 to 0.64% among ten cluster bean genotypes.

Iron: The genotypes showed significant variation in iron content, ranging from 120.25 ppm (GP-4) to 503.50 ppm (GP-12). Akcura et al (2020) reported a variation in iron content ranging from 88 ppm to 124 ppm across different genotypes of cluster bean.

Zinc: There was significant difference among the genotypes

Table 2. Mineral analysis of cluster bean genotypes

Treatments	K (%)	P (%)	Na (%)	Ca (%)	Mg (%)	Fe (ppm)	Zn (ppm)
IC-39980	1.10	0.12	0.21	**1.60**	1.02	284.00	33.25
IC-39981	1.71	0.02	**0.25**	0.65	1.02	365.00	**52.50**
Sikar	1.10	0.08	0.15	0.40	1.02	224.25	26.75
IC-39983	1.86	**0.20**	0.21	0.50	1.03	339.50	40.75
IC-39984	1.60	0.11	0.10	0.45	1.14	265.25	40.50
IC-39985	1.75	0.05	0.10	0.60	1.14	213.00	39.50
IC-39986	1.80	0.06	0.15	0.70	0.53	202.75	34.50
GP-19	1.65	0.11	0.15	1.10	1.20	208.50	33.50
GP-14	1.50	0.11	0.15	0.40	**1.69**	223.00	39.50
GP-4	1.00	0.04	0.15	0.50	1.68	120.25	36.25
PusaNavbahar	1.61	0.03	0.16	0.45	1.50	491.25	38.00
GP-20	1.36	0.04	0.15	0.60	1.50	207.00	31.00
VRCB-10	**1.95**	0.14	0.10	0.80	0.84	281.00	34.00
VRCB-57	1.41	0.04	0.15	0.70	0.73	278.50	33.50
GP-8	1.35	0.04	0.20	0.65	1.09	277.00	39.50
IC-11463	1.31	0.02	0.21	0.90	1.02	351.25	32.25
GP-12	1.65	0.02	0.10	0.80	1.14	**503.50**	48.00
VRCB-87	1.25	0.11	0.11	1.00	0.90	296.50	43.00
VRCB-47	1.50	0.02	0.15	0.50	1.68	204.00	28.00
KAU Suruchi	**1.95**	0.14	0.15	0.40	1.44	305.75	28.75
SEm (±)	0.004	0.002	0.003	0.022	0.005	0.503	0.172
CD (p=0.05)	0.011	0.006	0.009	0.066	0.014	1.489	0.509

Table 3. Minerals, deficiency disorders and nutritional significance

Minerals	Deficiency disorders	Nutritional significance	References
Potassium	Hypokalemia	Essential for maintaining fluid balance, supporting nerve transmission, muscle contraction, regulating blood pressure, and aiding in waste elimination	(Gharibzahedi and Jafari 2017)
Phosphorus	Hypophosphatemia	A key element in bones, cells, energy metabolism, and essential for DNA and ATP (as phosphate), as well as other vital functions	(Godswill et al 2020)
Sodium	Hyponatremia	Essential for maintaining proper electrolyte and fluid balance, supporting heart function, facilitating specific metabolic processes, and enabling muscle contraction and nerve transmission	(Gharibzahedi and Jafari 2017)
Calcium	Hypocalcaemia, osteoporosis, rickets	Helps to build and maintain strong bones and teeth, essential for maintaining heart, muscle, and digestive system	(Godswill et al 2020)
Magnesium	Magnesium deficiency, hypertension	Vital cellular element and the most abundant divalent cation, important for intracellular signalling, found in bones, regulates cellular functions by binding to proteins, nucleic acids, and nucleotides	(Weyh et al 2022)
Iron	Anaemia	Essential for haemoglobin formation in red blood cells, enabling oxygen transport; supports energy metabolism, electron transport within cells, and a key component of enzyme systems in tissues	(Gharibzahedi and Jafari 2017)
Zinc	Zinc deficiency	Plays a crucial role as a cofactor for over 300 enzymes, supports DNA, RNA, and protein synthesis, acts as an antioxidant, and maintains biological membrane stability, regulates hormone production	(Weyh et al 2022)

for zinc content, which ranged from 26.75 ppm (Sikar) to 52.50 ppm (IC-39981). Chhipa (2011) recorded a zinc content of 32.45 ppm in vegetable cluster bean.

CONCLUSIONS

The study highlighted several cluster bean genotypes with elevated levels of essential minerals, including VRCB-10 and KAU Suruchi for potassium (1.95%), IC-39983 for phosphorus (0.20%), IC-39981 for sodium (0.25%) and zinc (52.50 ppm), IC-39980 for calcium (1.60%), GP-14 for magnesium (1.69%), and GP-12 for iron (503.50 ppm). The results suggest that mineral-rich cluster bean genotypes could significantly contribute to improving human health by enhancing overall nutrition. As an underutilized leguminous vegetable, cluster beans are affordable and adaptable to adverse climatic conditions, making them a valuable resource for improving nutrition and enhancing food security.

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Small Loans, Big Impacts: Microfinance Pathway to SDGs, Climate Change and Energy Transitions

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***Abstract*:** The concept of microfinance, pioneered by Professor Muhammad Yunus and SEWA Bank in India, has evolved into a powerful tool for financial inclusion, bridging gaps between economic growth, environmental sustainability and energy transitions. With two primary delivery models *i.e.,* Self-Help Group Bank Linkage Programme (SBLP) and Microfinance Institutions (MFIs), microfinance has significantly impacted rural livelihoods, particularly among women. Strengthened by government schemes like DAY-NRLM, DAY-NULM and *e-shakti* (digitalization of SHGs), microfinance institutions in India have reached an all-time high of 53 million clients with a gross loan portfolio of ₹1,79,855 crores. It utilized government reports (e.g., MoSPI Annual Reports, Periodic Labor Force Survey, Sa-Dhan Microfinance Annual Reports from 2007-08 to 2022-2023), academic literature (peer-reviewed articles, research papers, case studies) and institutional data (reports from microfinance institutions, SHGs, NGOs). Through regression analysis, the study identified links between SHGs credit-linked, loan disbursement, loan outstanding, NPAs and NPA percentage to loan outstanding. CAGR analysis provides a region-wise overview of JLGs promotion and loan disbursement. The analysis of MFIs covered client numbers and loan portfolios, while trend analysis tracked regional changes in microfinance outreach, loan disbursement and repayment rates. the number of SHGs credit-linked surged to 42.96 lakhs from 12.28 lakhs in 2007-2008, marking a 17.07 per cent increase from the previous year. Bank loan disbursements saw a sharp 45.59 per cent growth, reaching ₹145 crores, up from ₹999 crores the previous year. Loans disbursed to SHGs and outstanding loans show a strong correlation (0.991), while decreasing NPAs signal a healthier economy. By analysing data using CAGR, the northern region leads in JLGs promotion with 54.71 per cent growth, followed by the western region at 52.46 per cent, while the north eastern region lags at 21.05 per cent. In loan disbursements, the eastern region tops with 68.15 per cent, followed by the northern region at 64.6 per cent and the north eastern region at 31.1 per cent.

***Keywords*:** JLGs, NABARD, SDGs, SHGs

Agriculture remains a vital pillar of India's economy, contributing 18.3 per cent to the GDP as per the Economic Survey of 2022-23. Despite its significance, the sector faces numerous challenges, with 45.76 per cent of the workforce engaged in agriculture as reported by MoSPI for 2022-23. Notably, women form a substantial part of this workforce, constituting 62.9 per cent as revealed in the Annual Periodic labor Force Survey of 2021-22. However, the majority of farmers are small &marginal, accounting for 86.21 per cent according to the agriculture census of 2015-16, with an average landholding size of just 1.08 hectares. Furthermore, the average, agriculture householding remains low at Rs. 8931 based on the NAFIS report of 2016-17. The data underscores the critical need for policy interventions to support and uplift India's agricultural sector.

The concept was created by *Professor Muhammad Yunus* founder of Grameen bank in Bangladesh and noble price winner in 2006. The Asian Development Bank (2000) defines microfinance as the provision of broad range of services such as savings, deposits, loans, payment services, money transfers and insurance to poor and low income households and their micro-enterprises. This definition of microfinance is not restricted to the below poverty line people but it includes low income households also.The taskforce on Supportive Policy and Regulatory Framework for Microfinance constituted by NABARD defined microfinance as “the provision of thrift, saving, credit and financial services and products of very small amount to the poor's in rural, semi urban and urban areas for enabling them to raise their income level and improve their standard of living” (Sen 2008).

MATERIAL AND METHODS

The study intends to examine the effectiveness of microfinance on sustainable development goals, climate change and energy transitions. In this we have taken the data of SHGs and JLGs over the years. The data for SHGs has been collected from secondary source through the status of microfinance in India yearly report published by NABARD from 2007-08 to 2022-23 and for JLGs we have collected data from 2014-15 to 2022-23. We have taken different aspects i.e., credit linkage, bank loan disbursed, bank loan outstanding, amount of NPA and percentage of NPA has been taken into account. We have also done the correlation analysis on the above aspects. The use of tables and graphs has been made to depict the data and progress of the various variables taken into account.

The compound growth rate has been calculated using the formula:

CAGR= [(Final value/Initial Value)^1/Number of years]-1*100%, Microfinance strengths, weaknesses, opportunities and threats are analysed by using SWOT analysis

RESULTS AND DISCUSSION

Evolution of Microfinance in India

1973 SEWA Bank, 1975 Rural Bank Ordinance, 1982 NABARD, 1990 SIDBI, 1992 SHG Bank Linkage Programme, 1999 Micro credit by SIDBI, 2006 MEDP by NABARD, AP Krishna Crisis, 2009 MFIN, 2010 Malegam Committee, 2011 NBFC MFI's, 2014 Universal Licensing for Bandhan Bank, 2015 MUDRA Bank & LEDP, 2021 BRICS Digital Financial Inclusion Report mentioned project e-shakti (Budampati and Sowmya 2022).

RBI regulates a wide array of financial entities, including commercial banks, RRBs, NABARD, cooperative societies and MFIs encompassing both NBFCs and NGOs. Microfinance in India lacks a unified regulatory framework, leading to a fragmented oversight system. Banks and Nob-Banking Financial Companies (NBFCs) while SHGs are overseen by the National Bank for Agriculture and Rural Development (NABARD). On the other hand, cooperatives are governed by the Registrar of Cooperatives Societies (RCS). This disparate regulatory environment creates challenges in ensuring consistent standards and practices across the microfinance sector.

The non-availability of credit and banking facilities to the poor and under privileged segments has always been a major concern. In response, the government and the RBI have implemented several initiatives, including the nationalization of banks in 1969, the perception of priority sector lending norms and the provision of concessional interest rates for the weaker sections of society. To address these challenges, the primary microfinance delivery models have emerged**:** the self-help group bank linkage programme and microfinance institutions.

Self-Help Group Bank Linkage Programme

A SHG is a democratically formed entity comprising 10-20 individuals from a homogenous class of rural and urban poor who belong to the same community or society and share a common economic goal. In this model, informal SHGs are linked with formal financial institutions to facilitate access to credit. There are three primary methods of providing loans: Model I- SHGs are both formed and financed by banks; Model II- SHGs are formed by agencies other than banks but receive direct financing from banks and model III- SHGs financed by banks through other agencies acting as financial intermediaries. This structure enables broader financial inclusion and support for economically marginalized groups.

As of March 31, 2022, information on 12.74 lakh self-help groups (SHGs) comprising 146 lakh members from over 1.73 lakh villages in 281 districts has been digitized under Project *e*-shakti as shown in Table 1. Additionally, starting July 1, 2021, data from 8.68 lakh SHGs in 130 districts across 15 states and one union territory is being updated monthly under a focused approach. The project has led to an improvement in credit linkages with banks. Before E-Shakti, 4.92 lakhs (or 39%) of digitized groups had credit linkages, but as of March 31, 2022, that number has increased to 7.17 lakh (or 56%) post *e- shakti* (Sarawagi and Singh 2024). SHG members also receive SMS alerts on their banking transactions in local languages, which has helped boost women's confidence in these groups. This demonstrates the success of digitization in SHGs, as well as their enhanced access to financial services. The programme was crucial in reducing SHGs' reliance on informal sources of financing.

Table 2 and 3 shows that the no. of SHGs credit linked, loan disbursed, loan outstanding, and the amount of loan are significantly correlated to each other, indicating that as the no. of SHGs credit linked increases, loan disbursed to them also increases and so does the increase in loan outstanding and amount of NPA. All these variables were highly significant ($P < 0.01$, 2 tailed). The highest correlation is between loan disbursed and loan outstanding (0.991), which is attributable to the fact that as the loan disbursement increases, there is a corresponding increase in loan outstanding because of various reasons such as accumulated interest, longer loan tenures as new borrowers are added, delayed repayments and roll-over of existing loans. The correlation between the number ofSHGs credit linked and loans disbursed and loans outstanding against SHGs is also very high (0.969 & 0.969, respectively). The reason could be the increase in the number of SHGs credit linkage due to digitization leading to the increase in demand for loans, thus, a higher volume of loan disbursement and loan outstanding. The percentage of NPA is negatively correlated to other factors because the amount of all other

Table 1. Digitalization of microfinance (*e-shakti*)

Year	Districts covered	Groups covered (in lakhs)
31.03.2016	2	0.08
31.03.2017	25	1.28
31.03.2018	100	3.49
31.03.2019	100	4.34
31.03.2020	254	6.44
31.03.2021	281	12.33
31.03.2022	281	12.74

factors considered was increasing due to the implementation of project e-Shakti except for the percentage of NPA which was decreasing and which is a good indicator.

Aajeevika-Deendayal Antodaya Yojana- National Rural Livelihood Mission (DAY-NRLM)

NRLM supported by world bank, launched on 3rd June 2011 to provide sharper focus & momentum for poverty reduction as also for achieving the Millennium Development Goals (MDG) by 2015 was renamed Deendayal Antayodaya Yojna-National Rural Livelihoods Mission (DAY-NRLM) w.e.f. November 2015. Components of Financial Inclusion are Interest subvention, SHG members as BC agents (BC Sakhis), Financial Literacy for SHGs (SAKSHAM centres), Digitalisation of SHG transactions (LoKOS App).

Deendayal Antodaya yojana- National Urban Livelihoods mission (DAY-NULM)

Government of India, Ministry of Housing & Urban Poverty Alleviation (MoHUPA), restructured the erstwhile Sawarna Jayanti Rozgar Yojna (SJSRY) & launched the National Urban Livelihoods Mission (NULM) in 2013 in all district headquarters (irrespective of population) and all the cities with population of 1 lakh or more. In 2016, it is renamed as Deendayal Antyodaya Yojana- National Urban Livelihoods Mission (DAY-NULM) by GoI.

Microfinance Institutions

The Microfinance Institution (MFI) model is globally recognized, whereas SHG-BLP is uniquely Indian. MFIs provide financial services to individuals or groups like SHGs ad institutions lend through the concept pf Joint Liability Groups (JLGs). A JLG is an informal group of 5-10 members who come together to avail bank loans, either individually or through groups mechanism against a mutual guarantee. MFIs can exist in various forms including trusts registered under the Indian Trust act, 1882/ Public trust act, 1920; societies registered under the Societies Registration Act, 1860; Cooperatives registered under the Mutual Aided Cooperative Societies Act of the states; non-banking financial companies (NBFC)- MFIs registered under Section 25 of the companies Act, 1956 and NBFCs registered with the

Table 2. Factors affecting SHGs

Year	No. of SHGs credit linked (in lakhs)	Bank loan disbursed to SHGs (Rs. in crores)	Bank loan outstanding against SHGs (Rs. in crores)	Amount of NPA of SHGs (Rs. in crores)	Percentage of NPA to the total loan outstanding against SHG
2007-08	12.28	8849.26	16999.91	422.93	2.49
2008-09	16.1	12253.51	22679.85	625.86	2.76
2009-10	15.87	14453.3	28038.28	823.04	2.94
2010-11	11.96	14547.73	31221.17	1474.11	4.72
2011-12	11.48	16534.77	36340	2212.73	6.09
2012-13	12.2	20585.36	39375.3	2786.93	7.08
2013-14	13.66	24017.36	42927.52	2932.67	6.83
2014-15	16.26	27582.31	51545.46	3814.71	7.40
2015-16	18.32	37286.9	57119.23	3686.23	6.45
2016-17	18.98	38781.16	61581.3	4002.19	6.50
2017-18	22.61	47185.88	75598.45	4628.06	6.12
2018-19	26.98	58317.63	87098.15	4524.01	5.19
2019-20	31.46	77659.35	108075.1	5321.7	4.92
2020-21	28.87	58070.68	103289.7	4889.21	4.73
2021-22	33.98	99729.23	151051.3	5743.71	3.80
2022-23	42.96	145200.2	188078.8	5249.34	2.79

Source: Compiled from Status of Microfinance report NABARD

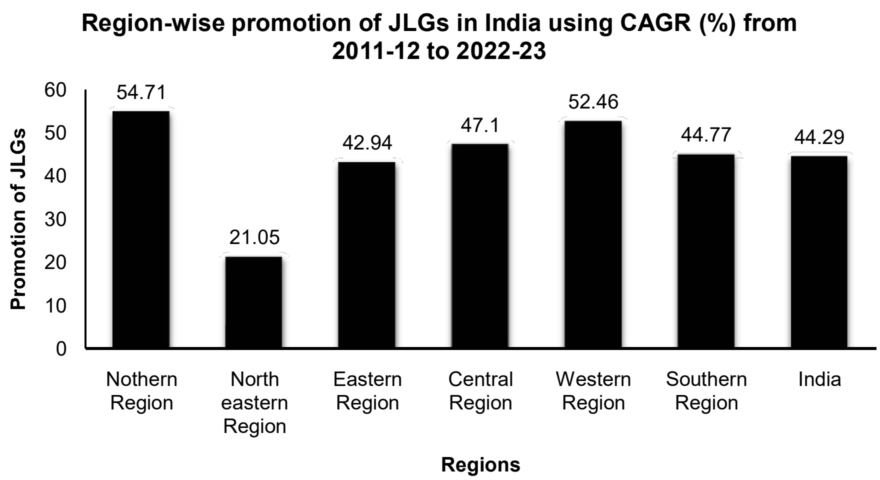
Table 3. Correlation among the factors considered

Factors	No. of SHGs credit linked	Loan disbursed to SHGs	Loan outstanding against SHGs	Amount of NPA
No. of SHGs credit linked	1			
Loan disbursed to SHGs	.969**	1		
Loan outstanding against SHGs	.969**	.991**	1	
Amount of NPA	.793**	.780**	.843**	1
Percentage of NPA to total loan outstanding	-0.332	-0.249	-0.205	0.283

**correlation is significant at the .01 level (2-tailed) reserve Bank. This diverse framework facilitates wider financial inclusion and support for economically marginalized communities (Myyizhi 2021).

Table 4 shows the latest data for 2022-23 reveals a significant rise in the promotion of Joint liability Groups (JLGs) totalling 257.92 lakh, marking a 37 per cent increase from the previous year's 187.92 lakh. Region-wise, the southern leads with the 31 per cent share, followed by eastern region at 30 per cent, central at 17 per cent, western at 12 per cent, northern at 9 per cent and north eastern at 2 per cent. This surge highlights the growing adoption of JLGs across India.

Table 5 shows latest data for 2022-23 reveals a significant rise in the loan disbursement to Joint liability Groups (JLGs)



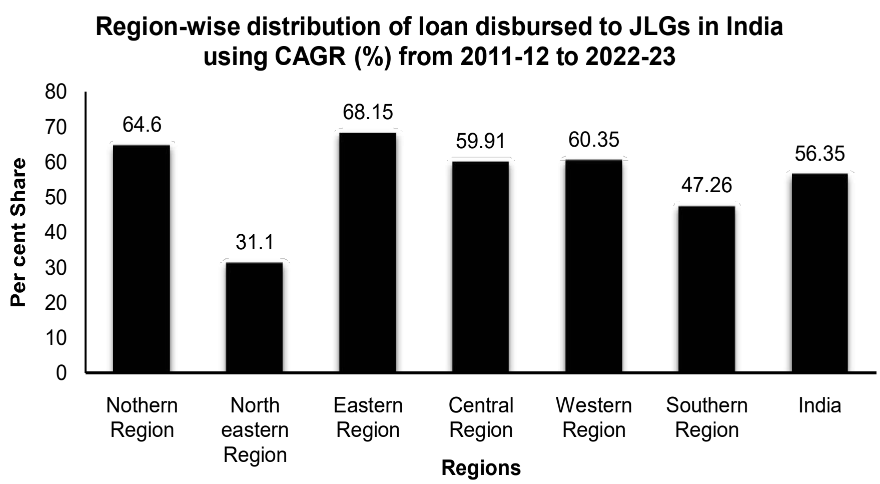


Table 4. Number of JLGs promoted

Year	No. of JLGs promoted (in lakhs)
2014-15	11.28
2015-16	17.52
2016-17	24.53
2017-18	34.53
2018-19	50.76
2019-20	92.56
2020-21	133.83
2021-22	187.92
2022-23	257.92

Source: Compiled from status of microfinance annual report by NABARD

Table 5. Amount of loan disbursed to JLGs

Year	Loan disbursed to JLGs (in crores)
2017-15	4414
2015-16	6161
2016-17	9511
2017-18	13955
2018-19	71750
2019-20	154853
2020-21	213614
2021-22	325938
2022-23	459310

totalling Rs. 459310 crores, marking a 41 per cent increase from the previous year's Rs. 325938 crores. Region-wise, the eastern region with the 36 per cent share, followed by southern region at 32 per cent, central at 14 per cent, western at 9 per cent, northern at 8 per cent and north eastern at 1 per cent. This surge highlights the loan disbursement to different JLGs across India.

Other services provided by Microfinance Institutions

1. MFI and Livelihood Interventions

ODISHA- Organization for Development of International Social & Health Action
CASHPOR Micro credit
Socio-economic Action Trust (SEAT)
Muthoot Microfin Ltd.
IIFL Samasta Finance Ltd.

2. MFIs and General Education Interventions

Satin Credit care Network Ltd.
Annapurna Mahila Coop credit Society Ltd.
REPCO Microfinance Ltd.
Digamber Capfin Ltd.
SAVE Microfinance Pvt Ltd.

3. MFI and preventive Healthcare Initiatives

SATYA Microcapital Ltd.
ASA International India Microfinance Ltd.
ODISHA
Muthoot Microfin Ltd.
Sonata Finance Pvt. Ltd.

Current Status and Growth of Microfinance in India

In 2023, a total of 213 Microfinance Institutions (MFIs) were reported, boasting a branch network of 25,790 and reaching all time high of 53 million clients with a gross portfolio of Rs. 1,79,855 crore, including a managed portfolio of Rs. 58,984 crore (Kumar 2015). According to Sa Dhan Bharat Microfinance Annual Report 2022-23, these MFIs cover 28 states, 5 union Territories and 646 districts serving 5.32 crore customers. In terms of geographical spread, Ashirvad Financial Services operated across 25 states helping in achieve SDG 10 (Reduced inequalities), surpassing Satin Microfinance's 24 states and Satya Microfinance's 22 states. Credit Access Grameen Ltd. Leads in loan portfolio with Rs. 21,031 crore supports SDG 1 (No poverty) by offering microloans that enable individuals to start or expand small businesses generating income and reduce poverty, followed by Shri KshethraDharmasthala Rural Development Project (SKDRDP) at Rs. 19,027 crore and IIFL Samasta Ltd. at Rs. 10,552 crore contributing to SDG 8 (Decent work and economic growth). The share of rural clientele notably increased during COVID-19 period, reflecting a shift in the microfinance landscape.

SWOT (Strengths, Weaknesses, Opportunities and threats) Analysis

Strengths

- Providing saving & credit facilities to poor and unreached people.
- Reduced dependence of poor people on informal money-lenders and non-institutional sources.
- Employment & income generation through micro-enterprises.
- Enhancing rural economic productivity through easy finances.
- Building up support system through non-financial assistance like technical support, skill development, training etc.
- Establishing the linkages between banks and marginalized citizens especially women.

Weaknesses

- Regional disparity in disbursement of credit across the country.
- High administrative cost.
- High repayment structure/high rate of interest.
- Multiple lending and over-indebtedness.
- Indiscipline among the borrowers for e.g. Dropout and migration of group members.
- No proper regulatory body & legal structure to check working of MFIs.
- Non-transparent pricing.
- Fight among MFIs to grab established markets.
- Inhuman behaviour of recovery of loans sometimes led to tensions even suicides.

Threats

- Cut throat competition among MFIs.
- MFIs vested interests like to grab the market lead to non-required lending even.
- Loans being provided for unproductive or unfeasible projects.
- Multiple loans to the same borrower lead to the same borrower lead to un recovery of loans.
- No use of SHGs peer pressure group for repayment.
- Opportunities
- Large number of people & areas in India are still uncovered.
- Various regions still untapped.
- Government & banks support to the programme.
- Range of services can be increased from financial to non-financial and others.
- Members can be helped to invest in asset creation, diversify their occupation & improve their risk bearing capacities.

Linkage between Microfinance and Sustainable Development Goals

Both in developed and developing countries, the agenda 2030 for sustainable development aims to end poverty, protect the planet and ensure all people enjoy peace and prosperity. India which hosted the G20 presidency for the first time in 2022, has intensified its focus in sustainable Development Goals (SDGs) through the digital transformation, a low-carbon economic model and a women led governance emphasizing gender equality and women's empowerment. According to global Multidimensional poverty Index 2022, 415 million people in India exited poverty between 2005-06 and 2019-21, indicating the possibility of achieving the SDG target (Vishwakarma 2024). Efforts to reduce poverty, empower women, assist vulnerable groups and improve the standard of living are building resilience to environmental, social and economic shocks and disasters as highlighted by the NatCat Insurance Index. Moreover, the RBI employs 5 C's approach- content, capacity, community, communication and collaboration to spread financial literacy with Financial Literacy Centres (FLCs) conducting 110,081 programs in 2022-23. Financial Literacy week in February 2023 focussed on themes such as saving, planning, budgeting and the responsible use of digital financial services. Programs like “Skilling and Financial Literacy Workshops” aim to educate rural populations. Additionally, gender equality initiatives, as reported by Micrometer, show that 99 per cent of loans disbursed to women were through cashless modes, with cashless collections increasing from 9 per cent to 11 per cent between Q3 FY21-22 and Q3 FY 22-23. These efforts underscore the importance of climate change action and energy transition in achieving the SDGs. Under SDG 5 (Clean water & Sanitation), India has made significant strides with the construction of over 100 million toilets under the “Swachh Bharat Mission” and 120 million water supply connections through the “Jal Jeevan Mission,” driving demand for water and sanitation loans. An awareness and income levels rise, climate-resilient structures such as rainwater harvesting systems, soak pits and all season accessible toilets have been established. Organizations like Nabsamruddhi (Nab Sam), DBS Bank and WaterEquityhave played a pivotal role in providing dedicated capital for WASH (Water, Sanitation and Hygiene) lending. In alignment with SDG 8 (Decent Work and Economic Growth) a study by NCAER titled “Present and Potential Contribution of Microfinance to India's Economy” revealed that the microfinance sector created about 1028 crores jobs, with NBFC-MFIs contributing 38.54 lakh jobs, significantly boosting employment generation. These efforts underscore India's commitment to climate change action and energy transitions, fostering sustainable growth and resilience.

CONCLUSION

Microfinance may not be a magic bullet but has emerged as a powerful tool, offering a wide range of financial and non-financial services, creating employment as a powerful, offering a wide range financial and non-financial services, creating employment opportunities and reducing gender and geographical disparities. Despite challenges such as such as slow graduation progress of SHG members, poor group functioning and member dropouts, initiatives like the e-shakti project have significantly increased SHG access to credit. This led to higher outstanding loan amounts and a decrease in the NPA growth rate, with the percentage of NPA to the total SHG loans outstanding also decreasing. Microfinance's impact spans several SDGs, creating domino effect that empowers people, reduces inequality and fosters sustainable economic growth. However, a lack of awareness about entrepreneurial benefits and reluctance to take risks have sometimes limited support for capable individual investing in start-ups. Addressing regional disparities can be achieved by promoting microenterprises through the Skill Upgradation for Women (m-Suwidha) initiative, emphasizing a 'vocal for local' approach. Expanding credit guarantees to SHGs and JLGs, fostering climate resilient microfinance and introducing micro pensions on a contribution basis are key steps forward. Additionally, enhancing skill development and building a digital ecosystem for SHGs will further drive sustainable growth and empower marginalized communities.

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Knowledge Gain through Instructional Videos among Tomato Growers of Central Plain Zone of Punjab, India

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Abstract: This study evaluated the effectiveness of instructional videos in enhancing tomato growers' knowledge of recommended cultivation practices. Utilizing Information and Communication Technology (ICT), the research involved 160 tomato growers from Amritsar and Patiala districts, selected through multistage sampling. Five targeted videos covering essential aspects of tomato cultivation were developed and presented to the respondents. The study measured knowledge levels before and after exposure to the videos, revealing a significant increase in knowledge retention. After exposure to the videos, 52.5 per cent of respondents achieved a high level of knowledge, a substantial rise from 22.5 per cent prior to the intervention, reflecting a notable 30.0 per cent shift in high knowledge levels. Additionally, respondents exhibited enhanced understanding in various aspects of tomato cultivation, including nursery raising, pest management, and irrigation practices. The findings highlight the efficacy of instructional videos as a powerful medium for agricultural education and underscore the role of ICT in effectively disseminating agricultural knowledge. Based on the positive outcomes, the study recommends the broader adoption of video-based learning tools to improve knowledge dissemination among farmers, ultimately contributing to better agricultural practices and productivity.

Keywords: Instructional videos, ICT in agriculture, Tomato cultivation, Information dissemination

The use of Information and Communication Technology (ICT) across various sectors of the global economy has proven to be a game changer in enhancing work efficiency and productivity. Agriculture is one sector that has benefited immensely from ICT integration. Daum (2020) concluded that, ICT has become pivotal for farmers in managing key production factors such as land, labor, capital, and soil. This technology is increasingly being utilized to address diverse challenges in agriculture, including prolonged droughts, pest outbreaks, seasonal variations, and the geographical dispersion of farming activities. Anh et al (2019) further highlight ICT's potential to mitigate issues like high transaction costs and information asymmetry in agriculture. Applying ICT throughout the agricultural value chain, from production to consumption, equips stakeholders with precise, timely, and relevant information. This not only enhances profitability but also promotes food security and sustainable agriculture (Purnomo and Lee 2010).

Farmers also use ICT platforms to provide feedback on new technologies based on their field experiences, which extension workers then relay to research institutions for further refinement (Nyarko and Kozári 2021). Digital extension methods, in use for many years in agricultural extension, play a critical role in this transformation. The application of ICT to tackle a wide range of development challenges has drawn significant attention from governments, practitioners, and researchers (Lwoga and Sangeda 2019, Arulkumar et al 2021, Acharya et al 2022). This shift toward digital tools not only enhances knowledge dissemination but also broadens access to agricultural information, contributing to the advancement of the agricultural sector. There is growing research on how ICTs are used in smallholder agriculture in developing countries, significant uncertainties remain regarding the effectiveness of emerging ICT-based approaches (Aker 2011, Nakasone and Torero 2016). This is particularly true in the realm of ICT-driven agricultural extension services aimed at improving farmers' management of crops, livestock, and natural resources. Previous studies have explored the impact of basic, cost-effective text and voice messaging services delivered via mobile phones, yet more advanced methods have received limited attention. These advanced approaches include the use of videos to convey information to farmers through intermediaries such as community organizers or extension workers, using tools like portable projectors, tablets, and computers. Videos, a relatively recent technological innovation in agriculture, hold great potential for addressing the challenges of information dissemination, particularly for the poor, marginalized, farm women, and young farmers. The application of videos in agriculture ranges from raising awareness and generating demand for support, to facilitating farmer-to-farmer extension, providing training on innovations, fostering creativity, and serving as tools for documentation, monitoring, and evaluation (Bentley et al 2015). Whether used independently or in conjunction with conventional extension approaches, videos stand out as a powerful medium for information dissemination (Abate et al 2019). The present study aims to assess the effectiveness of instructional videos in enhancing farmers' knowledge, specifically focusing on recommended tomato cultivation practices.

MATERIAL AND METHODS

Research design: In the present study, a quasi-experimental design was employed to estimate the effectiveness of instructional videos on the knowledge level of tomato growers regarding recommended practices for cultivation of tomato crop.

Location of study area: For the present study, two districts, Amritsar and Patiala, were purposively selected based on their highest area under tomato cultivation in the state (Department of Agriculture, Punjab 2023). Amritsar, located at 31.63°N latitude and 74.87°E longitude, with an elevation of 234 meters, experiences a semi-arid to subtropical climate and receives 500-600 mm of rainfall annually. Its well-drained alluvial soils are ideal for tomato farming. Patiala situated at 30.33°N latitude and 76.40°E longitude, at an elevation of 250 meters, experiences a similar climate, receiving 700 mm of rainfall per year. Its loamy to sandy loam soils also support significant tomato cultivation. A multistage sampling technique was used to select the blocks and villages. A total of 160 tomato growers were selected for the study.

Gain in knowledge: To evaluate this gain, five knowledge tests were developed, each covering crucial aspects presented in the instructional videos. These aspects included nursery raising, weeds and irrigation schedules, insect pest management, virus and diseases management and harvesting methods were prepared. These knowledge tests consisted of 21, 9, 15, 21 and 9 statements respectively. Each statement in these tests required respondents to provide answers in various formats, such as yes or no, fill in the blank, match the following and multiple-choice questions. A score of 1 was assigned to correct answers, while incorrect responses received a score of 0. Subsequently, the scores for each respondent were aggregated and based on the total scores, respondents were categorized into three knowledge levels by using range methods i.e. low, medium and high. After exposing the respondents to the videos, the post-exposure data was collected after a gap of 20-30 days. Total scores obtained by the respondents at the pre and post-test was be determined and the difference was calculated.

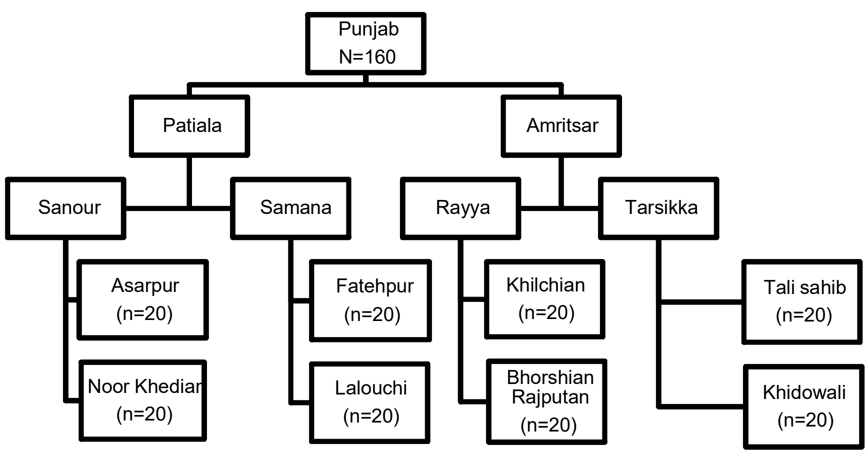
Gain in knowledge = $X2 - X1$

Where,

$X1$ = Test score in a pre-exposure test

$X2$ = Test score in a post-exposure test

Video description: In total, five videos were developed on various aspects of tomato cultivation. These videos have been submitted to the Department of Vegetable Science and the Communication Centre of Punjab Agricultural University, Ludhiana (PAU) for further dissemination and use in farmer outreach programs.



Video topic	Duration
Nursery raising	6 minutes and 27 seconds
Harmful effects of weeds and their management & irrigation scheduling	3 minutes and 43 seconds
Harmful effects and management of insect pests	3 minutes and 5 seconds
Harmful effects and management of diseases	4 minutes and 32 seconds
Harvesting stages of tomato fruit	2 minutes and 4 seconds

RESULTS AND DISCUSSION

Gain in knowledge of respondents regarding various practices of tomato cultivation: The study employed a pre-test to assess farmers' baseline knowledge of tomato cultivation practices before exposing them to instructional videos. A subsequent post-test evaluated knowledge gains, allowing for a comparison that quantified the effectiveness of the videos in enhancing understanding across key areas, including nursery raising, irrigation scheduling, weed management, pest control, disease management, and harvesting indices.

Nursery raising video: The soil solarization knowledge improved by 25.0 per cent, increasing from 36.3 to 61.3 per cent of respondents, while seed treatment before sowing knowledge showed an 18.1 per cent increase. Similarly, understanding of chemical seed treatment (Captan/Thiram) improved by 17.5 per cent. The most substantial gain was observed in the knowledge of using plug trays for raising seedlings, with a 28.1 per cent improvement, from 45.0 to 73.1 per cent.These shifts underscore the effectiveness of the videos in conveying critical information, as evidenced by a significant improvement in respondents' understanding of essential practices. The instructional videos were structured with visual aids and practical demonstrations, which

Exposure

Table 1. Knowledge gain before and after the exposure to instructional video on nursery raising (n=160)

Item	Before exposure (%)	After exposure (%)	% shift	Z test
Soil solarization	58 (36.3)	98 (61.3)	25.0	4.47*
Seed treatment before sowing	84 (52.5)	113 (70.6)	18.1	3.33*
Chemical used for seed treatment (Captan/Thiram)	71 (44.4)	99 (61.9)	17.5	3.14*
Recommended dose of Captan for seed treatment (3g/kg)	40 (25.0)	70 (43.8)	18.8	3.53*
Nursery area required to raise seedlings for an acre (2 *marla*)	90 (56.3)	110 (68.8)	12.5	2.31*
Raised nursery beds are recommended for raising nursery	124 (77.5)	141 (88.1)	10.6	2.52*
Plug trays are recommended for raising nursery	72 (45.0)	117 (73.1)	28.1	5.12*
Line to line spacing of seeds when sown in nursery beds (5cm)	52 (32.5)	89 (55.6)	23.1	4.17*
Optimum planting depth of seed (1-2 cm)	112 (70.0)	126 (78.8)	8.8	1.79
In plug tray, number of seeds sown per plug (1 seed)	43 (26.9)	76 (47.5)	20.6	3.82*
Mixture used in plug tray (cocopeat+ vermicompost+ perlite)	50 (31.3)	78 (48.8)	17.5	3.20*
The mulch applied in nursery should be removed after (5-7 days)	81 (50.6)	112 (70.0)	19.4	3.54*
Symptoms of damping off	102 (63.8)	108 (67.5)	3.8	0.71
Chemical used to control damping off (Captan)	52 (32.5)	81 (50.6)	18.1	3.29*
Recommended dose of Captan for damping off (4g/liter of water)	37 (23.1)	59 (36.9)	13.8	2.68*
Time of application (after 5-7 days of germination)	56 (35.0)	83 (51.9)	16.9	3.05*
The chemical should be repeated after (7-10 days)	41 (25.6)	70 (43.8)	18.1	3.41*
Withhold irrigation to strengthen seedling for better field establishment (4-5 days)	33 (20.6)	87 (54.4)	33.8	6.24*
Seedlings are ready for transplanting (4-6 weeks)	120 (75.0)	135 (84.1)	9.4	2.08*
Advantages of raising nursery in plug trays (higher germination, healthy plants with good root development etc.)	67 (41.9)	92 (57.5)	15.6	2.72*
Closed spacing of seedling leads to high incidence of insect-pests and diseases	67 (41.9)	93 (58.1)	16.3	2.91*

*Significant at 0.05 level

facilitated improved comprehension and retention. Smith et al (2020), also demonstrated that instructional videos significantly improved farmers' knowledge of best practices in crop cultivation. Similarly, Vasilaky et al (2015) and Van Campenhout et al (2017) reported significant gains in knowledge and technology adoption among farmers following video-based interventions. Moreover, increase was observed in respondents' awareness of chemical usage for controlling damping-off disease and the importance of withholding irrigation to strengthen seedlings. Jones and Patel (2018), Gupta et al (2019), and Rahman et al (2021) also mentioned a the positive impact of instructional videos on agricultural practices.

Initially, about 41.2 per cent of the respondents were categorized as having a low level of knowledge, 38.1 per cent had a medium level and 20.6 per cent had a high level of knowledge (Table 2). However, after watching the video, there was a significant change in knowledge level, about 46.2 per cent of the respondents falls in the category of high level of knowledge, 24.4 per cent were having a medium level and 29.4 per cent remained at a low level. This represents an increase of 25.6 per cent in the proportion of respondents achieving a high knowledge level following the video exposure. These changes were statistically significant at, highlighting the effectiveness of the video in enhancing the respondents' knowledge about nursery raising. Vikram (2000) and Pandian et al (2002) also demonstrated an increase in respondents' knowledge following exposure to farm videos.

Irrigation and weed management video: There was significant knowledge improvements among respondents regarding irrigation scheduling and weed management practices after exposure to instructional videos. Before viewing, only 55.0 per cent of respondents recognized that water deficit conditions adversely affect fruit size and quality, this figure rose to 70.0 per cent post-exposure, indicating a 15.0 per cent increase (Table 3). Similarly, awareness of the detrimental effects of waterlogging on plant roots increased from 33.1 per cent to 46.9 per cent, representing a 13.8 per cent gain. Knowledge of critical irrigation stages also

Table 2. Distribution of respondents on the basis of their level of knowledge before and after the exposure to the nursery raising video (n=160)

Instructional content in video	Level of knowledge	Before exposure (%)	After exposure (%)	% shift	Z test
Nursery raising	Low (0-7)	66 (41.2)	47 (29.4)	-11.9	2.21*
	Medium (8-14)	61 (38.1)	39 (24.4)	-13.8	2.64*
	High (15-21)	33 (20.6)	74 (46.2)	+25.6	4.85*

*Significant at 0.05 level

Table 3. Knowledge gain before and after the exposure to instructional video on the irrigation and weed management (n=160)

Items	Before exposure (%)	After exposure (%)	% shift	Z test
Under water deficit conditions, the tomato crop experiences a reduction in fruit size and a decline in tomato quality	88 (55.0)	112 (70.0)	15.0	2.77*
Water logging causes severe damage to plant by reducing supply of oxygen to the plant roots	53 (33.1)	75 (46.9)	13.8	2.52*
Critical stage of irrigation is flowering and fruiting stage	47 (29.4)	72 (45.0)	15.6	2.89*
Subsequent irrigation may be given after 6-7 days in summer	69 (43.1)	93 (58.1)	15.0	2.68*
Subsequent irrigation may be given after 14-15 days in winter	69 (43.1)	84 (52.5)	9.4	1.68
Recommended soil conditions for applying weedicide (Moist)	70 (43.8)	90 (56.3)	12.5	2.24*
Weed limit the growth of tomato plants due to competition for nutrient, light, water and space	82 (51.3)	101 (63.1)	11.9	2.13*
Pre-emergence application of weedicide to prevent weed (Sencor 70WP (metribuzin))	86 (53.8)	102 (63.8)	10.0	1.82
Recommended dose of Sencor (300g/200 liter of water)	57 (35.6)	69 (43.1)	7.5	1.37

*Significant at 0.05 level

improved, with respondents understanding that these occur during flowering and fruiting stages, which increased from 29.4 per cent to 45.0 per cent (15.6 per cent rise). Moreover, awareness of appropriate irrigation schedules was enhanced, with significant shifts observed in the understanding of timing for subsequent summer and winter irrigation. The findings illustrate a substantial shift in respondents' overall knowledge levels regarding irrigation and weed management practices, as a higher percentage demonstrated enhanced understanding post-exposure. Chen et al (2018) and Kumar et al (2020) also highlight the effectiveness of instructional videos in agricultural education. These statistically significant changes in knowledge levels affirm the videos' efficacy in bolstering essential skills related to irrigation and weed management, ultimately contributing to improved agricultural outcomes.

The study indicated that before exposure about 44.4 per cent of respondents had low level of knowledge about irrigation scheduling and weed management, followed by 37.5 per and 18.1 percent with a medium and high level of knowledge (Table 4). However, after exposure, 35.6 per cent of respondents have high level of knowledge followed by 32.5 and 31.9 per cent medium and low level. These findings suggest that the video on irrigation scheduling and weed management practices in tomato crops served as an effective intervention, increasing the proportion of respondents with a high level of knowledge by 17.5 per cent.

Insect-pest management video: The 32.5 per cent of respondents were having knowledge regarding the weed flora various areas serve as a reservoir for whitefly and aphids before exposure which increased significantly to 50.6 per cent after exposure. Understanding of the adverse effects of excessive nitrogenous fertilizer on insect pest multiplication improved by 20.6 per cent (Table 5). Additionally, awareness that seedlings are susceptible to pest infestation in the nursery rose from 52.0 per cent to 68.0 per cent after exposure.Awareness of the insecticide used to control whiteflies, Malathion 50 EC, increased by 6.3 per cent after exposure to the video. Knowledge of the recommended dose of Malathion (400 ml in 100 litres of water) rose from 38.1 per cent to 48.8 per cent, while awareness for aphids increased from 30.6 per cent to 45.0 per cent, indicating increases of 10.6 per cent and 14.4 per cent, respectively. Knowledge regarding the aphid-transmitted disease (Mosaic) rose significantly by 16.3 per cent. Understanding of insecticides used for fruit borer control increased from 79.4 per cent to 85.6 per cent. Additionally, there was about a 15 per cent increase in proportion of respondents regarding employing trap crops like marigold for fruit borer. Awareness of challenges in controlling insect pests saw a significant increase of 32.5 per cent.These results demonstrate the effectiveness of instructional videos in enhancing farmers' knowledge of insect-pest management, supporting findings by Palakkal and Chinnaiyan (2010) and Van Campenhout et al (2017).

The 40.6 per cent of respondents had a medium level of knowledge regarding insect-pest control in tomato crops, 37.5 per cent had a low level and 21.9 per cent had a high level of knowledge before exposure (Table 6). However, after exposure to the insect-pest control video, 47.5 per cent of respondents had a high level of knowledge, 29.4 per cent had a medium level and 23.1 per cent had a low level of knowledge. The findings reveal a significant shift of 14.4 per cent decrease in the proportion of respondents with a low level of knowledge and 25.6 per cent increase in those with a high level of knowledge. This indicates that the video was effective in enhancing the respondents' knowledge about insect-pest control in tomato crops. The calculated 'z' value confirms that these changes were statistically significant at the 0.05 level. These results underscore the effectiveness of informational videos as a tool for improving knowledge in agricultural practices. The substantial increase in the high knowledge category suggests that such interventions can play a crucial role in disseminating important information and improving farming outcomes. The results are in line with the findings of Cai (2015) and Chowdhury et al (2015).

Disease management video: There was significant enhancements in respondents' knowledge regarding disease management practices in tomato cultivation after exposure to

Table 4. Distribution of respondents on the basis of their level of knowledge before and after exposure to the irrigation and weed management video

Type of instructional content in video	Level of knowledge	Before exposure (%)	After exposure (%)	% shift	Z test
		f (%)	f (%)		
Irrigation and weed management	Low (0-3)	71 (44.4)	51 (31.9)	-12.5	2.30
	Medium (4-6)	60 (37.5)	52 (32.5)	-5.0	0.94
	High (7-9)	29 (18.1)	57 (35.6)	+17.5	3.53

*Significant at 0.05 level

instructional videos. Knowledge of disease transmission through infected seeds increased from 52.5 per cent to 66.3 per cent, reflecting a 13.8 per cent shift (Table 7). Similarly, awareness of seed treatment with fungicide rose from 46.3 per cent to 59.4 per cent, while understanding of disease prevention measures, such as crop rotation and soil sterilization, saw an increase from 38.1 per cent to 51.3 per cent. The knowledge of specific symptoms and control measures for diseases like early blight improved substantially, with recognition of symptoms rising from 49.4 per cent to 59.4 per cent. Moreover, significant shifts in knowledge regarding control measures for leaf curl and the impacts of monoculture practices on disease infestation were observed. The, awareness about the relationship between previous crop residues and late blight increased from 37.5 per cent to 61.9 per cent, marking a 24.4 per cent shift. Overall, the proportion of respondents with high knowledge levels rose dramatically from 18.1 per cent to 46.9 per cent post-exposure, indicating a profound impact of the instructional videos.

Forty-five per cent of respondents had a low level of knowledge about disease management, followed by 36.9 per cent with a medium level and 18.1 per cent with a high level

Table 5. Knowledge gain before and after the exposure to instructional video on insect-pest management

Item	Before exposure (%)	After exposure (%)	% shift	Z test
Weeds growing on field bunds, wastelands, roadsides and along irrigation canals serve as reservoirs for whiteflies and aphids.	52 (32.5)	81 (50.6)	18.1	3.29*
Excessive use of Nitrogenous fertilizer encourages multiplication of insect pests	35 (21.9)	68 (42.5)	20.6	3.95*
Tomato seedlings in the nursery are vulnerable to pest infestations, particularly from whiteflies.	83 (51.9)	109 (68.1)	16.3	2.97*
Regularly collection of infested fruits and destruction by burying them deep in the soil.	63 (39.4)	86 (53.8)	14.4	2.58*
Insecticide used to control whitefly (Malathion 50 EC)	114 (71.3)	124 (77.5)	6.3	1.27
Recommended dose of insecticide (400ml in 100 litres of water)	61 (38.1)	78 (48.8)	10.6	1.93
Leaf curl virus transmitted by whitefly disease	110 (68.8)	120 (75.0)	6.3	1.93
Insecticide used to control aphid (Malathion 50 EC)	90 (56.3)	104 (65.0)	8.8	1.23
Recommended dose of insecticide (400ml in 100 litres of water)	49 (30.6)	72 (45.0)	14.4	1.59
Aphid transmitted disease (Mosaic)	50 (31.3)	76 (47.5)	16.3	2.66*
Symptoms of fruit borer	140 (87.5)	156 (97.5)	10.0	2.97*
Insecticide used to control fruit borer (Coragen 18.5 SC/ Indoxcarb 14.5 SC/ Fame 480 SL)	127 (79.4)	137 (85.6)	6.3	3.40*
Recommended dose of insecticide (60ml/ 200ml/ 30ml)	50 (31.3)	73 (45.6)	14.4	1.46
Ideal trap crop for tomato fruit borer (Marigold)	78 (48.8)	103 (64.4)	15.6	2.63*
Facing challenges in effectively controlling insect pests (Change salt/insecticide)	58 (36.3)	110 (68.8)	32.5	2.82*

*Significant at 0.05 level

Table 6. Distribution of respondents on the basis of knowledge before and after exposure to the insect-pest management video

Type of instructional content in video	Level of knowledge	Before exposure (%)	After exposure (%)	% shift	Z test
Insect-pest management	Low (0-5)	60 (37.5)	37 (23.1)	-14.4	2.80*
	Medium (6-10)	65 (40.6)	47 (29.4)	-11.3	2.11*
	High (11-15)	35 (21.9)	76 (47.5)	+25.6	4.82*

*Significant at 0.05 level

before exposure to the video (Table 8). However, after watching the disease management video, 46.9, 31.9 and 21.3 per cent of respondents attained a high, medium level and low knowledge level. There was significant 28.8 per cent increase in respondents in the high knowledge category after exposure to the instructional video.

Table 7. Knowledge gain before and after the exposure to instructional video on disease management

Items	Before exposure (%)	After exposure (%)	% shift	Z test
Disease transmitted through infected seeds (Early blight, Damping off, Mosaic)	84 (52.5)	106 (66.3)	13.8	2.50*
Seed treatment with fungicide reduces the disease occurrence in initial stages of crop growth	74 (46.3)	95 (59.4)	13.1	2.35*
Disease prevention measures (follow long crop rotation, soil sterilization)	61 (38.1)	82 (51.3)	13.1	2.36*
Symptoms of early blight	79 (49.4)	95 (59.4)	10.0	1.80
Fungicide used to control early blight (Indofil M45)	123 (76.9)	131 (81.9)	5.0	1.11
Recommended dose of fungicide (600g)	60 (37.5)	80 (50.0)	12.5	2.25*
Repeat fungicide spray at interval of (7 days)	67 (41.9)	85 (53.1)	11.3	2.01*
Symptom of late blight	71 (44.4)	91 (56.9)	12.5	2.24*
Fungicide used to control late blight (Indofil M45) (Ridomil MZ 0.25%)	119 (74.4)	125 (78.1)	3.8	0.79
Recommended dose of fungicide (600-700g)	52 (32.5)	77 (48.1)	15.6	2.85*
Repeat fungicide spray at interval of (7 days)	60 (37.5)	104 (65.0)	27.5	4.92*
Previous crop residue causes late blight	60 (37.5)	99 (61.9)	24.4	4.36*
Trap crop for disease	76 (47.5)	96 (60.0)	12.5	2.24*
High rainfall and cool temperature favour the incidence of late blight disease	73 (45.6)	101 (63.1)	17.5	3.14*
Indofil M45 is effective in managing both Early blight and Late blight disease	54 (33.8)	89 (55.6)	21.9	3.94*
In leaf curl virus, plant remains unfruitful	82 (51.3)	112 (70.0)	18.8	3.43*
Control measures of leaf curl (Rouge out and burn affected plants)	53 (33.1)	91 (56.9)	23.8	4.27*
Swelling root galls is a symptom of root-knot nematode	123 (76.9)	158 (98.8)	21.9	5.98*
Green manuring with *Dhaincha* is not recommended in root-knot nematode infested fields	20 (12.5)	64 (40.0)	27.5	5.59*
Green manure with marigold in root-knot nematode infested fields	33 (20.6)	71 (44.4)	23.8	4.54*
Monoculture increase infestation of root-knot nematode	82 (51.3)	118 (73.8)	22.5	4.16*

*Significant at 0.05 level

Table 8. Distribution of respondents on the basis of knowledge before and after exposure to the disease management video

Instructional content in video	Level of knowledge	Before exposure (%)	After exposure (%)	% shift	Z test
Disease management	Low (0-7)	72 (45.0)	34 (21.3)	-23.8	4.51*
	Medium (8-14)	59 (36.9)	51 (31.9)	-5.0	0.94
	High (15-21)	29 (18.1)	75 (46.9)	+28.8	5.49*

*Significant at 0.05 level

Harvesting of tomato fruit video: There was significant enhancement in respondents' knowledge regarding harvesting practices for tomato cultivation following exposure to instructional videos. Knowledge about the importance of removing rotten, overripe, and borer-infested fruits for long-distance markets increased from 57.5 per cent to 73.8 per cent (Table 9). Additionally, understanding the necessity of avoiding harvesting immediately after chemical spraying improved from 66.3 per cent to 79.4 per cent. Post-exposure, respondents demonstrated advancements in post-harvest handling practices, with a 23.8 per cent shift in knowledge about pre-cooling fruits after harvesting and a 26.9 per cent shift regarding the total number of pickings based on various factors. The ability to identify the appropriate picking stages for different markets also saw significant improvements, with knowledge of local market requirements rising from 59.4 per cent to 80.6 per cent.

The 43.1 per cent of respondents belonged to the low knowledge level category, followed by 36.3 and 20.6 per cent in the medium and high knowledge level category (Table 10). However, after exposure to the harvesting indices video, approximately 53, 30 and 17.5 per cent of the respondents high, medium level and low level of knowledge. There was significant increase of 31.9 per cent in the proportion of respondents who achieved a high knowledge level after exposure to harvesting indices video.

Combined effectiveness of developed instructional videos on gain in knowledge: The combined effect of all instructional videos on the respondents' knowledge gain presented in Table 11. Before exposure to the instructional videos, 46.9 per cent of respondents had a medium level of knowledge followed by 30.6 per cent low level and 22.5 per cent high level of knowledge. However, after exposure to the harvesting indices video, about 53 per cent of the respondents demonstrated high knowledge, 30per cent medium knowledge, and 17.5per cent low knowledge. This indicates a significant shift, with about a 30 per cent increase in the proportion of respondents in the high knowledge level category and a 16.3 per cent decrease in the low knowledge level category. These findings suggest that the instructional videos significantly enhanced the respondents' knowledge levels.

Table 9. Knowledge gain before and after the exposure to instructional video on harvesting of tomato fruit

Items	Before exposure (%)	After exposure (%)	% shift	'z' test
For long distance markets, remove rotten, overripe and borer-infested fruits	92 (57.5)	118 (73.8)	16.3	3.06*
Avoid harvesting tomatoes immediately after chemical spraying any plant protection chemicals	106 (66.3)	127 (79.4)	13.1	2.64*
The fruits should be pre-cooled immediately after harvesting	26 (16.3)	64 (40.0)	23.8	4.72*
The total number of pickings depends on the variety grown, susceptibility to diseases and insect pests and prevailing environmental conditions.	73 (45.6)	116 (72.5)	26.9	4.89*
Shrink and cling film extends marketing period of tomato by increasing shelf life	26 (16.3)	66 (41.3)	25.0	4.94*
To hasten the ripening of harvested fruit, line plastic crates with newspapers	59 (36.9)	91 (56.9)	20.0	3.58*
For long distance market, pick mature green fruits	89 (55.6)	126 (78.8)	23.1	4.41*
For local market, pick fruit at ripen red stage	95 (59.4)	129 (80.6)	21.3	4.15*
For processing, pick when fruits are fully red	120 (75.0)	141 (88.1)	13.1	3.03*

*Significant at 0.05 level

Table 10. Distribution of respondents on the basis of knowledge before and after exposure to the harvesting of tomato fruit video

Instructional content in video	Level of knowledge	Before exposure (%)	After exposure (%)	% shift	'z' test
Harvesting of tomato fruit	Low (0-3)	69 (43.1)	28 (17.5)	-25.6	4.99*
	Medium (4-6)	58 (36.3)	48 (30.0)	-6.3	1.19
	High (7-9)	33 (20.6)	84 (52.5)	+30.0	5.92*

*Significant at 0.05 level

Table 11. Overall distributions of respondents on the basis of level of knowledge at before and after exposure to the developed instructional videos

Type of instructional content in video	Level of knowledge	Before exposure (%)	After exposure (%)	% shift	Z test
Farming practices of tomato crop	Low (≤ 25)	49 (30.6)	23 (14.4)	-16.3	3.48*
	Medium (26-50)	75 (46.9)	53 (33.1)	-13.8	2.51*
	High (≥ 51)	36 (22.5)	84 (52.5)	30.0	5.54*

*Significant at 0.05 level

The instructional videos utilized in the study engaged both visual and auditory senses, offering a multi-sensory learning experience to tomato growers. Few studies investigate the role of ICTs in providing production-related information. Notable exceptions include short message services delivering crop management advice and weather forecasts in India (Fafchamps and Minten 2012), integrated pest management in Ecuador (Larochelle et al 2019), agronomic advice in India (Cole and Fernando 2014) and timing advice for sugarcane farm operations in Kenya (Casaburi et al 2014). Additionally, animated videos on post-harvest management in Burkina Faso (Maredia et al 2017) and insecticidal neem use in Benin (Bello-Bravo et al 2018), as well as interactive crop advisory services via mobile phones in India (Fu and Akter 2012), have been studied. These studies report varied outcomes, ranging from no effects on production and yields (Fafchamps and Minten 2012, Dzanku et al 2022) to significant changes in input and technology use (Cole and Fernando 2014).

CONCLUSION

The study highlights the transformative potential of instructional videos in agricultural knowledge dissemination, particularly for tomato growers. The substantial increase in knowledge levels indicates that videos not only provide accessible information but also engage farmers effectively, leading to improved understanding of best practices. The results demonstrate that video-based interventions can play a critical role in bridging information gaps and improving agricultural practices among farmers. Furthermore, the findings emphasize the importance of incorporating modern communication technologies in agricultural training programs to enhance learning outcomes. Future initiatives should consider expanding the use of instructional videos across various agricultural sectors to maximize their impact on knowledge transfer and practice adoption.

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Varietal Diversity of Rice and Wheat in Subtropical North India

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Abstract: Rice (*Oryza sativa* L.) wheat (*Triticum aestivum* L.) cropping system (RWCS) is the largest grain production system in the world, including India. In India, with the introduction of high-yielding varieties of rice and wheat, RWCS emerged as the principal cropping system, ushering in the Green Revolution. However, the widespread adoption of higher-yielding varieties led to the loss of genetic diversity. A farm survey was conducted to analyse the on-farm varietal diversity of rice and wheat crops in the Jammu & Kashmir subtropics and Punjab. A multistage random sampling technique was applied to select a sample of 480 rice-wheat-cultivating farmers. In Punjab, 23 rice and 20 wheat varieties, and in Jammu, 17 rice and 19 wheat varieties were grown by the farmers. Ten and seven rice varieties were dominant varieties cultivated in Jammu and Punjab, respectively, covering a crop acreage of 76.40 and 46.86 per cent with a varietal diversity index of 0.131 and 0.106. In wheat, 88.75 per cent of wheat acreage was under two varieties with a varietal diversity index of 0.066 in the Jammu subtropics, and 82.02 per cent of total wheat acreage in Punjab was under five varieties with a mean varietal diversity index of 0.080.

Keywords: Rice-wheat cropping system, Varietal diversity, Jammu, Punjab

Rice (*Oryza sativa* L.) wheat (*Triticum aestivum* L.) cropping system (RWCS) is the largest agricultural production system in the world and covers 24 million hectares (m ha) area in Asia (Ladha et al 2000). In South Asia, RWCS covers an area of 13.5 m ha (Prasad 2005). In India, with the introduction of high-yielding varieties (HYVs) of rice and wheat, RWCS emerged as a principal cropping system, ushering in the Green Revolution. Overall, rice is cultivated in an area of nearly 43.8 m ha with a production of 177.6 Mt, and wheat acreage is 29.3 m ha area producing 103.6 Mt (FAOSTAT 2021) and is the backbone of India's Green Revolution. Out of this, the RWCS covers an area of around 9.2 m ha (Jat et al 2020). RWCS is the dominant cropping system in Punjab, Haryana, western Uttar Pradesh, parts of Bihar and sub-tropical areas of the Jammu region. However, sustainability issues about RWCS have emerged lately, such as high energy requirements, decreased water use efficiency, over exploitation of underground water, higher insect pest and disease infestation, loss of biodiversity, residue management and overuse of pesticides and nitrogenous fertilizers (Bhatt et al 2016, Peshin et al 2020).

World over, many studies conducted show varietal diversity in modern agriculture was reduced. With the advent of the Green Revolution, genetic diversity within and between the crop species has reduced. Post Green Revolution, many traditional rice varieties consumed prior to the Green Revolution have become non-existent (Nelson et al 2019). High-yielding varieties of rice and wheat were introduced as part of the Green Revolution to increase agricultural productivity replacing many local varieties (Pingali and Rajaram 1997). This resulted in reduced genetic diversity within a particular species (Keneni et al 2012). However, the Green Revolution mainly driven by HYVs of rice and wheat resulted in significant yield gains and is playing a decisive role in the world food supply to feed the growing population (Borlaug 2000).

The genetic and varietal diversity has narrowed in rice and wheat over time. The declining varietal diversity in rice and wheat is due to two fundamental concepts, namely, wide adaptation across locations, and consistent yield stability across years (Ceccarelli and Grando 2022). According to Ceccarelli et al (2013), only four varieties of rice are cultivated in 65 per cent of the world's total rice area. In Asia, two dominant varieties cover an overall area of 29 per cent in the case of cereals (Gatto et al 2021). Bangladesh and Vietnam lost varietal diversity in the rice and wheat (Muttaleb et al 2008, Jarvis et al 2008). Agricultural diversity can promote environmental health, resilience, and food production (Wolfe 2000). Crop species diversity is frequently highlighted as contributing to both nutritional security and ecological resilience (Reiss and Drinkwater 2018). It is more successful in pest management than single species or varietal stands because it contains colonies of natural enemies that protect crops (He et al 2019). Cropping systems with mixed varietal arrangements are more robust, particularly to biotic stress (Yang et al 2019). Varietal diversity has been shown to have a positive influence on dealing with abiotic stresses (Condori et al 2014) while posing a threat to food security. Heisey et al (1997) highlighted that few popular varieties cover large wheat acreage. In the recent past, wheat variety HD 2967 was the most popular wheat variety accounting for 11 per cent of wheat acreage in six states namely Haryana, Rajasthan, Bihar, Uttar Pradesh, Punjab, and Madhya Pradesh. Only five wheat varieties, namely, HD 2967, PBW 343, PBW 550, PBW 502 and Lok 1 accounted for major wheat areas in the six states mentioned above (Pavithra et al 2017). In this article, we have analyzed farm-level varietal diversity in RWCS in the Jammu subtropics and Punjab.

MATERIAL AND METHODS

Profile of the study area: The study was conducted in rice-wheat growing sub-tropical area of Jammu and Kashmir (J&K) and Punjab. Union Territory of J&K is in the northwestern Himalayan region. It has three distinct agro-climatic zones namely sub-tropical Jammu region (up to 800 meters above mean sea level), intermediate/semi-temperate mid-hills (800-1500 meters above mean sea level), and temperate (1500-2500 meters above mean sea level). In J&K, only sub-tropical area of Jammu region was selected for the study. Punjab is also located in sub-tropical zone and its average elevation is 300 meters above mean sea level with a range from 180 meters in the southwest to more than 500 meters around the northeast border (Anonymous 2024).

Sampling plan: A multistage sampling technique was used to draw the sample of farmers. In Punjab, six districts were selected using a proportionate random sampling technique from the three regions of Malwa, Majha and Doaba. The districts were: Barnala, Ludhiana, Mansa and Moga in the Malwa region; Gurdaspur in Majha region and Kapurthala in Doaba region (Fig. 1). From the sub-tropical Jammu region, three representative districts namely Jammu, Samba and Kathua were selected purposively (Fig. 1). In each selected district of Punjab, two blocks were selected randomly. The blocks selected were Barnala and Tappa from Barnala district; Pakhowal and Khanna from Ludhiana district; Bhikhi and Budhlada from Mansa district; Moga I and Moga II from Moga district; Derababa Nanak and Dinanagar from Gurdaspur district, and Kapurthala I and Sultanpur Lodhi from Kapurthala district. In the subtropical Jammu region, four blocks each were selected from Jammu, Samba and Kathua districts. R.S Pura, Bishnah, Marh and Jourian were selected from Jammu district; Ghaghwal, Vijaypur, Ramgarh and Rajpura from Samba district, and Barnoti, Nagri, Marheen and Hiranagar from Kathua district.

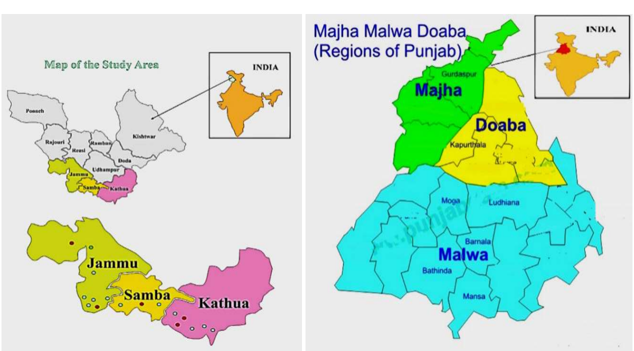


Fig. 1. Location of surveyed villages in the subtropical Jammu region and in Punjab

Further, from the selected blocks, a list of villages practising rice-wheat cropping systems was prepared. Simple random sampling without replacement technique was applied to select two villages from each block. A total number of 48 villages (24 villages each from Jammu and Punjab) were chosen for the study. Lists of the farmers cultivating rice-wheat crops were prepared by meeting Sarpanches/ progressive farmers of each village. From the lists prepared, a sample of 10 farmers was drawn from each village by employing random sampling without replacement. Thus, a total sample size of 480 farmers was selected for the study (Table 1). The data were collected through the personal interview method with the help of two semi-structured interview schedules from the sampled farmers.

Descriptive statistics of farmers: The descriptive statistics of farmers are given in Table 2. The average age of farmers in the Jammu region and Punjab was 51.68 and 45.34 years respectively. The average formal education of Jammu farmers was 9.75 years whereas Punjab farmers' average education was 10.36 years. A majority of farmers of Jammu and Punjab were literate. The average farm size of Jammu farmers was 1.97 ha with an average farming experience of 31.68 years whereas, Punjab farmers' average operational landholding was 6.31 ha (that includes: owned landholding of 4.71 ha and leased-in landholding of 1.61 ha) with farming experience of 25.34 years (Table 2).

Measurement of extent of adoption: The adoption of rice and wheat varieties/hybrids was measured by the percentage of farmers cultivating and the area under a crop variety.

Measurement of varietal diversity: For estimation of varietal diversity of rice and wheat varieties, Theil's entropy index (1972) was used.

$$E = \sum_{i=1}^{n} P_i \log(1/P_i)$$

Where,

E is the entropy index,

P i is the proportion of area under i^{th} variety to total area under the crop (rice/wheat),

n is the number of varieties raised by the farmers

Statistical analysis: A z-test of proportion was applied to compare the proportions from two independent groups to determine if they were significantly different from one another. Two sample t-test was used to compare means from independent samples from rice and wheat growers of Jammu and Punjab to test whether the two samples differ significantly in their mean concerning socio-personal and biophysical variables.

RESULTS AND DISCUSSION

Extent of adoption of rice and wheat varieties/hybrids: In Jammu subtropics, the extent of adoption with respect to area coverage was dominated by hybrid rice (54.04%) followed by basmati varieties, coarse varieties, and semi-fine varieties. However, in Punjab, major rice acreage was under coarse varieties (53.42 %), followed by hybrid rice, basmati varieties and semi-fine varieties. In Jammu, the major rice varieties cultivated or adopted in 2021-22 were Basmati 370 (48%) followed by Pusa Basmati 1121 and in Punjab Pusa 44 and PR 121 (Table 3). In the Jammu sub-tropics, though 19 wheat varieties were cultivated by the farmers, only one variety namely HD 2967 covered an area of 81.53 per cent of wheat acreage and two varieties HD 2967 and HD 3086 covered 88.75 per cent of wheat acreage. In the case of Punjab, 20 wheat varieties were cultivated but three varieties namely HD 2967, HD 3086 and WH 1105 covered an area of 71.23 per cent of total wheat acreage . The extent of adoption of HD 2967 and HD 3086 concerning the percentage of farmers was 94 per cent in Jammu. In Punjab, the extent of adoption of HD 2967 and HD 3086, with respect to farmers was 81 per cent (Table 3).

In the case of rice crop, though the number of varieties cultivated by the farmers in Jammu and Punjab were 17 and 23 respectively, however, the varieties with more than five per cent of crop acreage were only nine in the Jammu sub-tropics and seven in Punjab (Table 3). On the other hand, in the case of wheat, only two varieties were cultivated on more than five per cent of wheat acreage in the Jammu sub-tropics. In Punjab, five varieties were cultivated on more than five per cent of the wheat acreage.

Varietal diversity of rice-wheat: In 2020-21, 23 rice varieties/ hybrids were cultivated by the farmers of Punjab. Out of which, seven rice varieties/hybrids were cultivated on more than five per cent of rice acreage (Table 3). In 1984-85 and 1990-91, nine rice varieties were cultivated, which two major rice varieties were PR 106 and Jaya. PR 106 was cultivated in 57 per cent area in 1984-85, which decreased to 41 per cent (1987-88), again increased to 62 per cent (1990-91) and then declined to 23 per cent (1998-99) (Singh and Kalra 2002). The other variety was Jaya, cultivated in an area of 20 per cent in 1984-85 which further increased to 25 per cent (1985-86) and then decreased to nine per cent (1990-91) (Singh and Kalra 2002). Thereafter, in 1990-91 and 1998-

Table 1. Sampling plan

State/Region	Districts selected	Blocks selected	Villages selected	Farmers selected from each village	Total
Sub-tropics of Jammu	3	12	24	10	240
Punjab	6	12	24	10	240
Total	9	24	48	10	480

Table 2. Descriptive statistics of sampled farmers

Parameter	Jammu (n=240)	Punjab (n=240)	Difference
Average age (in years)	51.68±0.65	45.34±0.70	6.34 (t=6.59*)
Literate (% farmers)	96	99	03 (z=2.1*)
Average formal schooling	9.75±3.49	10.36±2.46	0.61 (t=2.83)
Education level (% farmers)			
i. Upto Primary (1-5)	05	04	01 (z=0.3)
ii. Upto Middle (6-8)	15	08	07 (z=1.6)
iii. Upto Matriculation (9-10)	51	55	04 (z=0.6)
iv. Upto Senior secondary (11-12)	17	23	06 (z=1.1)
v. Graduate and above	08	09	01 (z=1.1)
Average family size	6.01±0.17	5.87±0.11	0.14 (t=0.69)
Average farming experience of respondent farmers (years)	31.68±0.66	25.34±0.70	6.34 (t=6.60*)
Average operational landholding (ha)	1.97±0.16	6.31±0.36	4.34 (t=11.13*)

*Significant at p≤ 0.05

Table 3. Extent of adoption of rice and wheat varieties/hybrids with respect to percent farmers and area (2021-22)

Rice variety/ hybrid	Jammu	Punjab	Jammu	Punjab	Wheat variety	Jammu	Punjab	Jammu	Punjab
	(% farmers)[1]		(% area)			(% farmers)[1]		(% area)	
Basmati variety			32.00	15.19	HD 2967#	87	28	81.53	17.42
Pusa 1121#	45	10	5.77	5.45	HD 3086#	7	53	7.22	47.70
Basmati 370#	48	-	11.22	-	HD 3226#	2	1	1.2	0.07
Un-descript (Komo Basmati)	6	-	6.87	-	PBW 175#	1	-	0.35	-
Pusa 1718	1	5	5.00	0.43	RAJ 3765#	1	-	0.01	-
Pusa Basmati 1509#	-	4	-	3.65	RAJ 3077#	1	-	0.2	-
Pusa 1401/ Muchhal Basmati	-	2	-	5.66	WH 1105#	1	8	0.5	6.11
CSR-30#	1	-	3.12	-	HD 3043#	2	3	0.54	1.96
Semi- fine variety			4.98	2.55	PBW 550#	1	3	0.20	1.33
Sharbati	15	3	2.48	2.55	PBW 723	1	-	0.2	-
Devgoda	4	-	2.5	-	HD 1553	1	-	0.2	-
Coarse variety			8.97	53.42	JK Vijay	1	-	0.2	-
Jaya#	2	-	2.34	-	Ankur	3	-	4.64	-
Pusa 44	-	60	-	9.7	HD 2329	1	1	0.05	0.75
PR 106	-	1	-	3.65	PBW 343#	1	1	0.15	0.40
PR113#	11	-	6.63	-	PBW 644	1	-	0.50	-
PR 114#	-	2	-	5.20	DBW 168	1	-	1.0	-
PR 118#	-	1	-	7.30	DBW 222#	1	1	0.25	0.60
PR 121#	-	30	-	6.25	HS 507	3	-	1.07	-
PR 122#	-	2	-	3.65	DBW 187#	-	5	-	3.80
PR 126#	-	11	-	3.79	HD 2687	-	3	-	3.1
PR 127#	-	2	-	4.01	PBW 725#	-	3	-	2.7
PR 128#	-	3	-	3.65	PBW 118	-	1	-	0.24
PR 129#	-	1	-	2.55	Shree Ram 272	-	3	-	5.27
PR 201	-	1	-	3.65	DBW 173#	-	1	-	0.15
Hybrid			54.04	28.82	Krishna	-	1	-	0.12
Arize 6444	1	-	5.62	-	DBW 88#	-	1	-	0.30
BH 21	1	-	2.5	-	JK 5501	-	1	-	0.66
Dhanya 748	4	-	7.60	-	Ganga	-	8	-	5.52
Dhanya 834	2	4	8.44	3.28	Sunehri#	-	1	-	0.15
HKR 47	-	1	-	7.30					
HK 100	1	-	7.50	-					
Hybrid 28P67	-	1	-	4.37					
Kaveri 468	-	1	-	2.2					
Paddy 105	-	1	-	3.65					
PHB 71#	1	-	3.75	-					
Sawa 127	1	-	10.00	-					
Super hybrid 901	-	1	-	3.65					
Tata RIL 666	-	1	-	4.38					
VNR 2355	3	-	8.62	-					

Notes: #Resistant/recommended varieties. [1] Multiple responses. Figures corresponding to percentage of famers have been rounded up to the nearest whole number

99, 12 rice varieties were cultivated, out of which two major rice varieties were cultivated namely PR 111 and Pusa 44. PR 111 was cultivated in an area of four per cent in 1995-96 which further increased to 26 per cent (1998-99) and Pusa 44 was cultivated in an area of six per cent (1991-92) which increased to 27 per cent (1998-99) (Singh and Kalra 2002). In 2016, 18 rice varieties were cultivated in Punjab, out of which three major rice varieties, namely, Pusa 44, Basmati 1121 and PR 121 were cultivated on an area of 27.23, 23.0 and 20.71 per cent of rice acreage respectively (Peshin et al. 2017; Peshin et al. 2023). Over time, the number of rice varieties cultivated by the Punjab farmers has increased. The results of this study revealed that Punjab farmers had cultivated 23 rice varieties in 2021-22 (Table 3). In Jammu subtropics, seven rice varieties were cultivated by farmers in 2016, out of these, Basmati 370 was the dominant variety (58.49%), followed by PR 113 (16.13%) and Pusa 1121 (12.42%) (Peshin et al 2017). However, another study conducted by Bano (2019), reported that about 17 rice varieties were cultivated in 2016, and the dominant varieties were: Basmati 370 and Basmati 1121. The result of this study show that 16 rice varieties were cultivated (which include hybrids) and the dominant varieties cultivated were Basmati 370 (11.22%), Basmati 1121 (5.77%) and PR 113 (6.63%).

In the case of wheat, the area sown has constantly increased in Punjab from about 28 per cent (mid-1980s) to 42 per cent (1990-91) to 50 per cent (1995-96) and further to 62 per cent in 1998-99 (Singh et al 2004). The varieties which were cultivated namely C 303 and C 306 covered 70 per cent of the area under wheat up to the mid-1960s. Later, Kalyan Sona (K 227) and PV 18 (semi-dwarf varieties) dominated through the mid-1970s. In 1970-71 and 1980-81, 17 wheat varieties were cultivated, out of these only 3 major wheat varieties namely Kalyan Sona (K 227), WG 357 and WL 711 were cultivated widely. In 1970-71, Kalyan Sona alone covered 80 per cent of the wheat area in 1975-76. From 1980-81 to 1989-90, 19 wheat varieties were cultivated out of which, 2 major wheat varieties were WL 711 and WL 1562 were cultivated. In 1980-81, WL 711 variety covered 73 per cent of wheat acreage which later decreased to one per cent only (1995-96) and WL 1562 variety was cultivated in an area of 22 per cent (1984-85) which also decreased to one per cent only by 1996-97 (Singh et al 2004). From 1990-91 to 1998-99, the number of wheat varieties cultivated decreased to 13. It was observed that there were two major wheat varieties namely HD 2329 and PBW 343. HD 2329 had an area of 80 per cent (1990-91) which later increased to 86 per cent (1993-94) and then decreased to 11 per cent (1998-99) and at the same time PBW 343 covered 82 per cent (1998-99) and further increased to 86 per cent in 1999-2000 (Singh et al., 2004). A review of the literature shows, that only 2-3 varieties dominated the area coverage at different points in time.

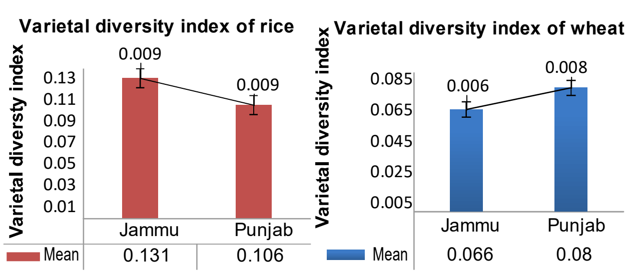


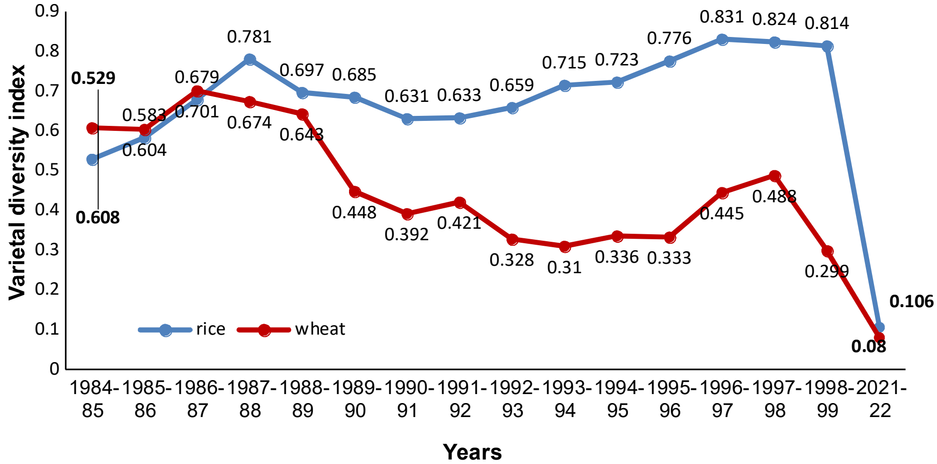
Fig. 2. Varietal diversity index of rice and wheat crops in the subtropical Jammu and Punjab 2021-22

In the case of subtropics of Jammu, around 19 wheat varieties were cultivated in 2013-14, the five dominant wheat varieties were RAJ 3077 (33.23%) followed by hybrid JK Vijay (28.68%), PBW 550 (16.14%), PBW 175 (14.51%), PBW 343 (14.12%) (Peshin et al 2014). However, Bano (2019) reported that farmers cultivated around 11 wheat varieties which include HD 2967 (occupied 72% of wheat acreage) followed by PBW 550 (11.27%). The results of this study show that around 19 wheat varieties were cultivated by farmers, out of which, 81.53 per cent was under HD 2967 and 7.22 per cent under HD 3086.

From the above-reviewed literature and the results of this study, it can be concluded that the number of rice varieties cultivated at the farm level has increased both in Punjab and in the sub-tropics of Jammu and there have always been two to three dominant varieties in Punjab since 1980-81 and no change was observed in 2021-22. Unlike Punjab, in Jammu subtropics, the number of dominant varieties (with more than 5% of wheat acreage) has decreased and only two varieties were covering more than five per cent of wheat acreage (Table 3).

Varietal diversity index: The varietal diversity of rice and wheat varieties was measured on Theil's entropy index (1972). The varietal diversity index of rice in Jammu and Punjab was 0.131 and 0.106 respectively, and in the case of wheat, the varietal diversity index of Jammu and Punjab was 0.066 and 0.080 respectively in 2021-22. The varietal diversity index shows that in Jammu subtropics, the mean varietal diversity index of rice was higher as compared to Punjab with a difference of 23 per cent (Fig. 2). But, in the case of wheat, the varietal diversity index was higher in Punjab compared to the sub-tropical Jammu with a difference of 21 per cent (Fig. 2). The varietal diversity of rice was higher than wheat in the Jammu subtropics and as well in Punjab.

The varietal diversity of rice has decreased in Punjab from 0.529 in 1984-85 to 0.106 in 2021-22, a decrease of 80 per



(Data source: 1984-85 to 1998-99 Singh and Kalra 2022; Singh et al 2004; 2021-22 own data)

Fig. 3. Varietal diversity of rice and wheat in Punjab overtime

cent whereas in the case of wheat, the varietal diversity has decreased from 0.608 post-green revolution (1984-85) to 0.080 in 2021-22, a decrease of 86.8 per cent (Fig. 3).

CONCLUSION

From the study, it is concluded that over time, in the case of rice crop, the varietal pool has increased resulting in more than five per cent of rice acreage under each of the six rice varieties and thus, higher varietal diversity. Besides, there is diversity in different rice types cultivated by the farmers such as basmati, semi-fine and coarse rice. Unlike rice, in wheat, the varietal pool is narrow as only two to three varieties covered more than 71.23 per cent of wheat acreage in Punjab and in the case of Jammu; only two wheat varieties covered 88 per cent of wheat acreage. The varietal diversity of rice and wheat in Punjab has also decreased by more than 80 per cent over time. The decrease in varietal diversity reduces the resilience from the biotic and abiotic stresses. Further, research is needed to study why the varietal diversity of wheat is lower than rice.

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Adoption Behaviour of Vegetable Growers Towards Post Harvest Management Practices in Punjab

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Abstract: This study investigates the adoption behavior of vegetable growers towards post-harvest management practices in Nakodar, Malerkotla, and Baba Bakala Sahib, Punjab, India, using a survey of 240 growers. The 59.17% of farmers have a favorable attitude towards post-harvest practices, recognizing their role in reducing spoilage and enhancing market value. The application of the Theory of Diffusion of Innovation (DOI) demonstrated medium knowledge levels among potato (56.9%) growers, and lower levels for tomato (49.2%), cauliflower (37.5%), okra (41.5%), and pea (50.2%) growers. Only 58.62% adopted recommended harvesting methods for potatoes, while none followed proper tomato harvesting techniques, resulting in post-harvest losses. The 94.32% of cauliflower growers and 80.90% of okra growers practiced grading. Stepwise regression analysis indicated that 27% of the variation in knowledge was influenced by social participation, age, extension activities, and economic orientation. The study emphasizes the need for targeted extension programs to enhance farmers' knowledge of storage and transportation practices, alongside promoting low-cost storage technologies and skill training in post-harvest management to minimize losses and improve profitability.

Keywords: Post-harvest losses, Knowledge, Adoption, Vegetable growers

The United Nations' 2015 Sustainable Development Goals (SDGs) emphasize sustainable consumption and production patterns, focusing on more efficient production and supply chains. Annually, about one-third of the world's food production is lost or wasted. The Food and Agriculture Organization (FAO) aims to reduce food loss and waste along supply chains, including post-harvest stages (FAO 2022). Vegetables, being highly perishable, experience significant losses due to suboptimal post-harvest practices, such as harvesting, sorting, packaging, storage, and transportation (Viswanadham 2007).

India has seen remarkable growth in horticulture, with the area under cultivation increasing by 2.6% and production by 4.8% annually over the past two decades. Between 1991-92 and 2020-21, vegetable production rose from 58.5 million tonnes to 199.88 million tonnes, positioning India as the second-largest vegetable producer after China. Punjab, a leading state in horticulture, with 3.06 lakh hectares under vegetable cultivation and contributes significantly to national food security and exports (Thind and Mahal 2021). The world's population is expected to reach 10.5 billion by 2050, increasing food demand by 60% (Alexandratos and Bruinsma 2012). To meet this demand, reducing post-harvest losses is essential. In India, post-harvest losses of vegetables are estimated at 30-40%, costing approximately Rs. 2 lakh crore annually (Negi and Anand 2016). Losses in tomatoes, beans, and eggplants are particularly high, with rates exceeding 10% at the producer level (Sharma and Singh 2011).

Post-harvest losses occur due to various factors, including poor infrastructure, lack of storage facilities, and insufficient farmer knowledge of proper handling techniques (Kumar et al 2004). While some farmers regularly adopt practices like sorting, grading, and safe transportation, others lack awareness of more advanced post-harvest methods, such as cooling and modern packaging. In a study conducted by Sidhu et al (2024), the maximum losses were observed in tomato crop at farm level (17.71%) and retailer level (30.10%) whereas at wholesaler level maximum losses were recorded in pea (8.19%). Maximum losses were observed in tomato crop (17.71%) followed by cauliflower (6.79%), okra (5.57%), pea (5.2%) and potato (4.44%). The extent of losses at farm level has been higher as compared to wholesaler level and the highest at the retailer level. Studies indicate that 56% of farmers have a medium level of knowledge about post-harvest practices, but significant gaps remain in the adoption of optimal methods (Azad et al 2014, Ghanghas et al 2017). Addressing these gaps requires improving infrastructure and farmer education on post-harvest management. The present study was conducted in Punjab, India with objective to appraise stages undergone in the adoption of post-harvest management practices of among the vegetable growers.

MATERIAL AND METHODS

Study area: The study was conducted in Nakodar (Jalandhar), Baba Bakala Sahib (Amritsar) and Malerkotla

(Sangrur) of Punjab during the year 2020. Vegetables selected for the study were potato, pea, cauliflower, tomato and okra. In Amritsar district, the Baba Bakala Sahib cluster is known for cultivating potatoes. In Jalandhar district, the Nakodar cluster specializes in growing peas, tomatoes, and okra. Meanwhile, in Sangrur district, the Malerkotla cluster is focused on cultivating cauliflower and okra.

Selection of sample: Snowball sampling technique was employed for selection of respondents from every cluster to get respondents for all selected vegetables. Eighty farmers from each cluster were selected (240 farmers). Roger's innovation decision model was used to appraise stages undergone in the adoption of post-harvest management practices of among the vegetable growers. The information was collected on socioeconomic profile of the farmer (Table 1). The knowledge test for each selected crop was prepared regarding post-harvest management practices such as harvesting and collection, cleaning, grading and packaging.

Items with difficulty index between 0.25 to 0.75 and discrimination index (Di) above 0.20 were selected for knowledge test (Thorndike and Thorndike-Christ 2010). Cronbach alfa reliability of the test calculated was 0.925 which was significant at 1 % level of probability. Item analysis was done to select the items for final attitude scale. Scores for all attitude items were calculated for each farmer and arranged from highest to lowest. The upper and lower level groups were defined as the top five and bottom five farmers, respectively, representing 50 percent of the total. The mean scores for each item were computed for both groups. Items exhibiting the largest discrepancies between the means of the two groups were selected for the final scale. Specifically, items with a discrepancy value of 0.8 or greater were retained, while those below this threshold were excluded. This selection process utilized Murphy and Likert's methodology (Edward 1969), focusing on the magnitude of the difference between the means of high and low groups for each statement. Additionally, the 't-value' for each statement was calculated using Edward's formula.The items analysis was done in order to select the statements for final version of the scale with value of t equals to:

$$t = \frac{\bar{X}_H - \bar{X}_L}{\left[\dfrac{\Sigma (x_H - \bar{x}_H)^2 + \Sigma (x_L - \bar{x}_L)^2}{n(n-1)}\right]^{1/2}}$$

Where,

t = A measure of the extent to which a given statement differentiates between the high and low group

X_H= Score of given statement of individual for higher group

$\bar{X}_H$ = Mean score on a given statement for higher group

X_L= Score on same statement of individual for lower group

$\bar{X}_L$= Mean score on a given statement for lower group

n = The number of subjects in high group = The no. of subject in low group

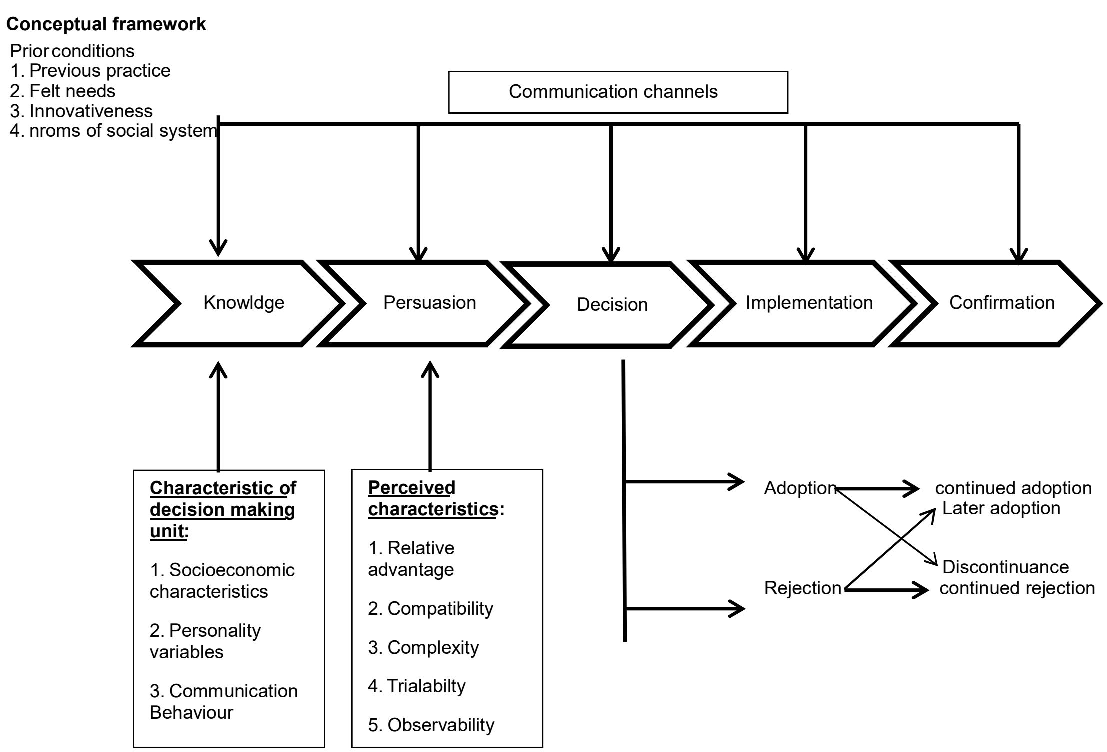

Fig. 1. Roger's innovation decision model (Rogers 1983)

The final selection of the items was done on the basis of the magnitude of difference between mean of higher group and mean of lower group for individual item and 't' value of that item. The items yielding t-value less than 1.75 were not included in the final scale. From original scale consisting of 35 items, only 10 items were retained in the final scale.

Statistical analysis: Data were analysed using Statistical Package for the Social Sciences (SPSS) software, version 23.0.

RESULTS AND DISCUSSIONS

Socio economic characteristics of vegetable growers: The socio economic characteristics of vegetable growers are given in Table 1.

Knowledge level of vegetable growers regarding post-harvest management practices: The farmers growing potatoes, tomatoes, cauliflower, okra, and peas have varying levels of knowledge about post-harvest management practices, with many lacking crucial information. In the case of potato farmers, 56.9, 38.7 and 4.3% had a medium low high level of knowledge. Although most farmers were familiar with the recommended techniques for harvesting and grading, but lacked awareness of the proper storage conditions and the optimal time period for storing potatoes under controlled environments.

Tomato: Among tomato farmers, 49.2, 37.3 and 13.4 % possessed low, medium knowledge, and high level of knowledge. Framers were aware of the harvesting time but did not understand the best method for determining fruit maturity, relying on size and color rather than cutting the fruit crosswise and were also unfamiliar with proper temperature regulation for washing and drying, and although they knew about waxing, they did not understand its purpose or technique. None of the farmers knew the storage requirements for tomatoes.

Cauliflower: For cauliflower farmers, 37.5, 30.6 and 7.9% had low , medium and high knowledge. They were aware of cutting tools but lacked the proper technique for cutting. Though familiar with grading, the harvesting index, and packaging, most cauliflower farmers lacked knowledge of proper storage and transportation practices.

Okra: Among okra farmers, 41.5, 34.8 and 23.6% had low, medium and high knowledge. Farmers knew the harvesting index, the number of pickings, and recommended packaging materials, but lacked understanding of suitable containers for collection, leading to bruising and blackening. Moreover, they lacked knowledge of temperature regulation and humidity requirements for storing okra.

Pea: The pea farmers showed a similar pattern, with 50.2% having low knowledge, 40.4% having medium knowledge, and only 9.2% having high knowledge of post-harvest practices. They were familiar with the harvesting index, pickings for different maturity varieties, and packaging materials, but most did not know about tools like the tendrometer for checking maturity and were unaware of proper storage requirements for peas.

Farmer's knowledge of ideal time of harvesting the vegetables scored first rank with mean score of 3.10. Knowledge about different techniques of harvesting with mean score of 1.87 and harvesting stage of vegetables with

Table 1. Distribution of the vegetable growers according to their socio-personal characteristic

Socio-personal characteristics	Mean ± Standard deviation
Age	44±11
Education	3.43±1.17
Occupation followed	1±0
Operational land holding (Acres)	27.94±18.20
Farming experience (Years)	22.90±11.21
Participation level in extension activities	5.91±4.50
Level of Social participation	2.60±1.95
Level of extension contacts	12.48±7.32

n=240

Table 2. Distribution of farmers based on their knowledge of post-harvest management practices

Category	Range	Frequency (f)*	Percentage (%)
Potato (n=116)			
Low	2-5	45	38.7
Medium	5-8	66	56.9
High	8-11	3	4.3
Tomato (n=67)			
Low	5-8	33	49.2
Medium	8-11	25	37.3
High	11-13	9	13.4
Cauliflower (n=88)			
Low	3-5	33	37.5
Medium	5-7	27	30.6
High	7-9	7	7.9
Okra (n=89)			
Low	11-13	37	41.5
Medium	13-15	21	23.6
High	15-17	31	34.8
Pea (n=173)			
Low	3-5	87	50.2
Medium	5-7	70	40.4
High	7-9	16	9.2

mean score of 1.54 scored second and third rank respectively. Knowledge of farmers about temperature regulation for storage of vegetables scored last rank with mean score of 1.09.About 54.6 % of the farmers possessed low level of knowledge. About 39.6 and 5.83 % of the farmers fall in medium and high category of knowledge respectively. Farmers possessed high level of knowledge regarding time of harvesting of vegetables while they lacked knowledge about temperature regulation required for storage of vegetable crops.

Factors affecting vegetables knowledge regarding post-harvest management practices in vegetables: Stepwise regression analysis indicated that 27% of variation in knowledge of vegetable growers was determined by level of social participation (X1), age (X2), participation level in extension activities (X3) and level of economic orientation (X4). This relationship is described in the following formula: Y= -0.363X1+ -0.266X2+ 0.248X3+ 0.164X4. Participation level in extension activities and level of economic orientation have positive and significant effect on knowledge of vegetable growers regarding post-harvest management practices since through extension activities.

Adoption of recommended post-harvest practices: There were significant variations in the adoption of recommended post-harvest practices among farmers growing potatoes, tomatoes, cauliflower, okra, and peas. Potato farmers showed a mixed approach, with 58.62% using the recommended potato digger for harvesting, while others used spades, leading to the harvest of immature green potatoes. Farmers in Malerkotla and Nakodar adopted the recommended harvesting methods, whereas those in Baba Bakala Sahib used spades. None of the farmers followed cleaning practices, as middlemen collected the produce directly from the farms. For tomato harvesting, none of the farmers followed the recommended technique of lifting, twisting, and pulling the fruit. Instead, they directly pulled the tomatoes, leading to post-harvest losses. Cleaning practices with chlorinated water or dry cloth were not followed, as farmers washed the fruits with normal water after packing them in plastic crates. Sorting and grading were performed by 89.55% of farmers, while the rest packed all fruits, including damaged ones, without proper sorting. Despite using recommended plastic crates, no cushioning of fruits during transportation was done due to a lack of awareness. In cauliflower farming, all farmers followed the recommended harvesting method using a sickle and trimmed extra leaves for cleaning. Grading was done by 94.32% of farmers, and all packed the cauliflower tightly in recommended polythene bags for marketing. Among okra growers, none followed the recommended practice of harvesting with a clean knife; instead, they pulled the okra by hand. Grading was followed by 80.90% of farmers, and 89.89% used recommended polythene packaging, while others opted for gunny bags due to availability. Among, pea farmers, the recommended harvesting method was followed by all, but only 8.67% of farmers practiced grading due to the extra labor required. All farmers used the recommended red mesh bags for packaging, but none stored peas as they were unaware of the storage requirements and available technologies for proper storage.

Attitude of farmers towards post-harvest practices: The 59.17% of farmers have a favorable attitude towards post-harvest practices of vegetables, recognizing that these practices can reduce spoilage and increase the market value of their produce. Some farmers also expressed a positive attitude towards the need for training in post-harvest

Table 3. Distribution of the farmers according to their knowledge regarding various aspects of post-harvest management practices (n=240)

Knowledge statements	Response mean	Standard deviation
Knowledge about harvesting stage of vegetables grown by you	1.54	0.64
Knowledge about different techniques of harvesting vegetables	1.87	0.69
Ideal time of harvesting vegetables	3.10	0.95
Knowledge about temperature regulation for storage of vegetable crops	1.09	0.30

Table 4. Regression analysis of factors affecting vegetables knowledge regarding post-harvest management practices in vegetables

Independent variables	Dependent variables	Standard error	Coefficients	'p' value
Level of social participation (X1)	Knowledge regarding post-harvest management practices	.044	-0.363	.000
Age (X2)		.008	-0.266	.000
Participation level in extension activities (X3)		.012	0.248	.000
Level of economic orientation (X4)		.033	0.164	.005

R2 = 0.272

*significant at the 0.05 level,**significant at the 0.01 level

Table 5. Distribution of farmers on the basis of adoption of recommended post-harvest practices (n=240)

Practice	Frequency (f)*	Percentage (%)
Potato (n=116)		
Harvesting	68	58.62
Cleaning	0	0
Grading	14	12.06
Packaging	116	100
Tomato (n=67)		
Harvesting Method	0	0
Cleaning	0	0
Sorting /grading	60	89.55
Packaging	67	100
Cauliflower (n=88)		
Harvesting method	88	100
Cleaning	88	100
Grading	83	94.32
Packaging	88	100
Okra (n=89)		
Harvesting method	0	0
Grading	72	80.90
Packaging	80	89.89
Pea (n=173)		
Harvesting method	173	100
Grading	15	8.67
Packaging	173	100

*Multiple response

techniques and establishing freezing facilities for vegetables. However, many farmers showed an unfavorable attitude towards setting up rural industries for processing and storage to prevent distress sales. Additionally, there was limited positive attitude towards proper handling of vegetables at the farm level to reduce spoilage. Out of 240 farmers, 59.17% had favorable attitudes, Similar. positive attitude of farmers towards various aspects of post- harvest technologies was reported by Barua et al (2017).

CONCLUSION

The study concludes that vegetable growers have significant knowledge gaps in post-harvest practices, despite recognizing their importance in reducing spoilage and increasing market value. Only 59.17% of farmers had favorable attitudes towards post-harvest management and the need for training, many lacked knowledge on storage and transportation precautions. Adoption of recommended practices varied by crop, with medium knowledge among potato growers but lower levels for other crops. Factors such as participation in extension activities and economic orientation positively influenced farmers' knowledge.

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Identifying Agricultural Opinion Leaders as Transformation Agents Using Social Network Analysis

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***Abstract*:** This study explores the identification of opinion leaders within farming communities using social network theory, aiming to enhance agricultural extension efforts. Conducted across three villages in Ludhiana, Punjab, data were gathered from 214 farmers using the sociometric method. Five opinion leaders from each village, determined by the highest in-degree centrality scores, were identified through social network analysis using UCINET. Results show that these opinion leaders, central in the communication network, tend to be older, better educated, and possess larger landholdings than general farmers. Social network diagrams were developed for each village, and 15 opinion leaders were selected overall. While the frequency of consultations with these leaders varied, in-degree scores across villages indicated a similar leadership level. These findings suggest that experience, education, and land ownership are significant factors in establishing opinion leadership within agricultural communities, making these leaders essential resources for guiding and shaping farming practices.

***Keywords*:** Communication network, Network centrality, Opinion leaders, Social network analysis, Sociometry

In today's agricultural context, various farm technologies are being developed by institutions like State Agricultural Universities, ICAR, ICRISAT etc. However, the true advancement of agriculture depends not just on technological innovation, but predominantly on the willingness of farmers to adopt these new technologies (Bala 2000). This presents a significant challenge, particularly as many farmers are often illiterate and deeply rooted in traditional practices, making them resistant to change or adopt innovations (Thakur 2022). Convincing them to adopt new technologies requires the intervention of external agents, such as extension agencies. However, their efforts are hampered by practical constraints like the large size of agricultural communities and farmers' distrust of outsiders.

In such a scenario, individuals within farmers' social networks who hold influence can serve as effective catalysts for instigating necessary changes. These individuals, called Opinion Leaders, play a pivotal role in disseminating innovations within agricultural communities (Rogers 2003). Bala (2000) and Saju (2021) concluded that disseminating innovations significantly improves when extension personnel collaborate with opinion leaders, who can informally convince others within their community. Indeed, the success of development initiatives often depends upon the receptiveness of opinion leaders compared to their followers. Consequently, in such scenarios, the role of change agencies becomes secondary in facilitating technology diffusion. The role in disseminating information and facilitating knowledge exchange enhances farming efficiency, promotes agricultural knowledge sharing, and enriches the decision-making process by reaching a broader audience of farmers. Hence, by leveraging the influence of opinion leaders, extension agencies can effectively bridge gaps in agricultural knowledge dissemination and facilitate the adoption of innovative practices, particularly in areas with limited official support. Rogers (2003) observedthat opinion leaders are crucial in guiding innovations to the point at which a necessary threshold of social network users has embraced them, further increasing adoption and self-sustainability.

With the advent of advanced technologies, there has been an explosion of application of social network theories and their applications to various disciplines. The sociometric technique is the most widely used data collection method for identifying opinion leaders, which involves asking respondents to nominate individuals they consider leaders. Typically, this technique, along with interviews, observations, and other observational methods, is employed to pinpoint opinion leaders in social networks. Individuals receiving the most nominations are designated as opinion leaders. Another common method is the Informants' Rating Method, which gathers insights from influential members of society. Snowball sampling is also effective, particularly for collecting information from hidden or specialized populations, as it helps identify members of these often-concealed groups Additionally, the self-designation method is used, where individuals assess their own perceived leadership qualities.As stated by Merwe and Heerden (2009) and supported by Borgatti (2006), social network theories simplify the identification of opinion leaders by constructing relational networks, where individuals occupying central positions are regarded as key influencers. Basera and Bharadwaj (2022) applied social network theory to analyze agricultural knowledge exchange among farm women in Uttarakhand, India. The study identified 24 opinion leaders with high in-degree centrality, revealing that their leadership was shaped by factors such as age, marital status, farming experience, socio-economic status, and behavioural traits like innovativeness, decision-making ability, and social participation. The study was planned to find opinion leaders from farmers' social networks and to compare their socio-personal attributes to see if any difference exists between these opinion leaders and general farmers in Punjab.

MATERIAL AND METHODS

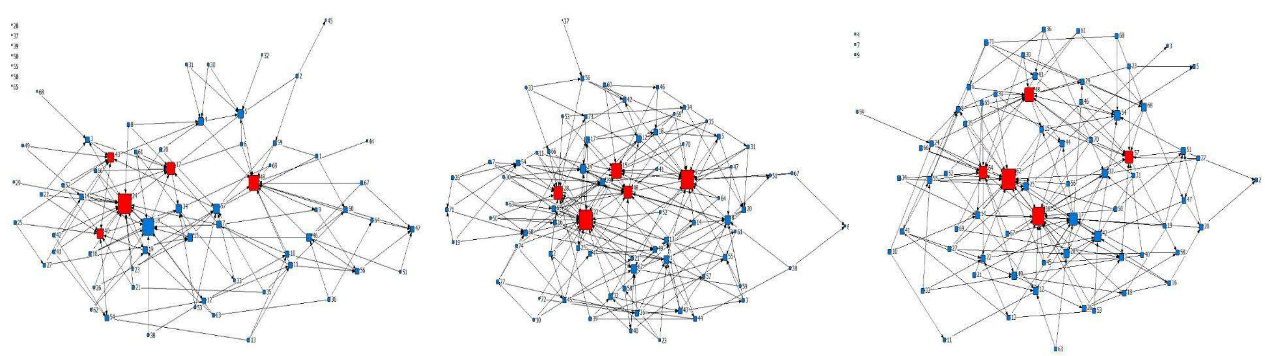
The study was conducted in 2023 across three villages in the Sidhwan Bet block of Ludhiana, Punjab, selected through a multi-stage sampling method. Then, villages with less than 100 farmers were identified, leading to the selection of Gorahoor (30.9311ºN, 75.5885ºE) (69 farmers), Bharowal Kalan (30.9159ºN, 75.5820ºE) (74 farmers), and Talwara (30.9446ºN, 75.5358ºE) (71 farmers), totalling 214 farmers under rice-wheat cropping pattern. Data was collected using a pre-tested semi-structured interview schedule that was pre-tested and refined based on a pilot study. Personal interviews were conducted, incorporating sociometric questions to gather social network data using the "who-to-whom" technique. Farmers were asked to name up to three individuals they frequently consulted for agricultural advice. UCINET (version 6.05), was used to analyze the social network data to calculate respondents' degree centrality (in-degree). UCINET, developed by Steve Borgatti, Martin Everett, and Lin Freeman in 2002, for analyzing social network data and to calculate respondents' degree centrality (in-degree). Degree centrality refers to the number of direct connections a node (individual who can have a relationship with other individuals within the social network) has with the other nodes. This study calculated the in-degree network centrality measure using SNA to find the opinion leaders. In-degree network centrality of an individual was measured as the total number of individuals who approached him/her to obtain information. The top five respondents from each village with the highest in-degree scores were identified as opinion leaders. Social networks were visualized using NetDraw, providing insights into the flow of agricultural information within the communities. To better understand the key differences between general farmers and opinion leaders, socio-personal variables such as age, education and land holding were also studied.

RESULTS AND DISCUSSION

Social network analysis and opinion leadership: Social network diagrams for each village were created using NetDraw, (Fig. 1a-c). In Gorahoor, the in-degree scores ranged from 0 to 19; in Bharowal Kalan, from 0 to 20; and in Talwara, from 0 to 22. The top five farmers with the highest in-degree centrality scores in each village were identified as opinion leaders. Specifically, these were nodes 17, 24, 40, 43, and 48 in Gorahoor; nodes 9, 15, 22, 28, and 48 in Bharowal Kalan; and nodes 38, 48, 57, 62, and 64 in Talwara. There were significant variations in their influence (Table 1).

Table 1. Centrality measures (in-degree) of opinion leaders in selected villages

Particulars		Gorahoor	Bharowal Kalan	Talwara
		In degree score		
Opinion leaders (in-degree score)	I	10	20	17
	II	19	16	12
	III	9	20	11
	IV	9	14	22
	V	14	12	11
OL (Average in-degree score)		12.2	.4	14.6
F-value			1.22^{NS}	



a b c

Fig. 1. Social Network graph of villages (a) Gorahoor, (b) Bharowal Kalan and (c) Talwara

Fifteen farmers were identified as opinion leaders across the three villages, the frequency with which other farmers consulted them varied considerably. However, the average in-degree scores across villages did not show significant differences, indicating a similar level of opinion leadership within each community.

Impact of socio-personal variables: The socio-personal variables provided insight into the demographic characteristics of the farmers and opinion leaders in the study (Table 3, 4). The 47% of the opinion leaders fall within the 56-70 age group, with another 40% in the 42-55 age category (Table 3). Opinion leaders also had higher levels of education, with 60% having completed higher secondary education and 20% having completed matriculation. The significant majority (66.66%) of the opinion leaders owned large landholdings (>10 hectares), with only 6.66% owning

Table 2. Distribution of respondents (Farmers) according to their socio-personal characteristics

Parameters	Categories	Gorahoor (n_1=64)	Bharowal Kalan (n_2=69)	Talwara (n_3=66)	Total (n=199)
Gender	Male	60 (93.75)	67 (97.10)	64 (96.97)	191 (97.97)
	Female	4 (6.25)	2 (2.90)	2 (3.03)	8 (2.03)
Age	(28 - 41)	23 (35.93)	27 (31.88)	27 (40.91)	77 (36.36)
	(42 - 55)	23 (35.93)	22 (28.99)	19 (28.79)	64 (32.66)
	(56 - 70)	18 (28.12)	20 (18.84)	20 (30.30)	58 (29.64)
Education	Primary education	7 (10.93)	8 (12.69)	4 (18.18)	19 (9.54)
	Secondary education	4 (6.25)	5 (7.24)	9 (13.04)	18 (9.45)
	Matric	29 (45.31)	26 (37.68)	29 (43.93)	84 (42.21)
	+2	14 (21.88)	22 (31.88)	16 (27.27)	52 (26.13)
	Graduation	10 (15.62)	8 (11.59)	8 (12.12)	26 (13.06)
Land holding	Marginal (<1 ha)	8 (12.50)	7 (10.14)	5 (7.57)	20 (10.05)
	Small (1-2 ha)	11 (17.18)	19 (27.53)	14 (21.21)	44 (22.11)
	Semi-medium (2-4 ha)	14 (21.87)	9 (13.04)	18 (27.27)	41 (20.60)
	Medium (4-10 ha)	19 (29.68)	24 (34.78)	20 (30.30)	63 (31.65)
	Large (>10 ha)	12 (18.75)	10 (14.49)	9 (13.63)	31 (15.57)

Figures in parentheses indicate percent

Table 3. Distribution of respondents (Opinion leaders) according to their socio-personal characteristics

Parameters	Categories	Gorahoor (n_1=5)	Bharowal Kalan (n_2=5)	Talwara (n_3=5)	Total (n=15)
Gender	Male	5 (100)	5 (100)	5 (100)	15 (100)
	Female	-	-	-	-
Age	(28 - 41)	1 (20)	-	1 (20)	2 (13.33)
	(42 - 55)	2 (40)	2 (40)	2 (40)	6 (40)
	(56 - 70)	2 (40)	3 (60)	2 (40)	7 (46.66)
Education	Primary education	-	-	-	-
	Secondary education	-	-	-	-
	Matric	-	2 (40)	1 (20)	3 (20)
	+2	3 (60)	3 (60)	3 (60)	9 (60)
	Graduation	2 (40)	-	1 (20)	3 (20)
Land holding	Marginal (<1 ha)	-	-	-	-
	Small (1-2 ha)	-	-	-	-
	Semi-medium (2-4 ha)	-	1 (20)	-	1 (6.66)
	Medium (4-10 ha)	2 (40)	1 (20)	1 (40)	4 (26.66)
	Large (>10 ha)	3 (60)	3 (60)	4 (80)	10 (66.66)

Figures in parentheses indicate percent

medium-sized holdings and one leader having semi-medium holdings. Comparing these two groups, several key differences emerge. e the farmers' age distribution was relatively balanced, with a slight skew towards younger age groups, opinion leaders were predominantly older. This age disparity suggests that experience and tenure may play a role in establishing opinion leadership within these communities. Educationally, opinion leaders were generally better educated than the average farmer, which may enhance their credibility and influence. Moreover, the landholding data highlight a stark contrast. most farmers had medium-sized holdings; opinion leaders primarily possessed large landholdings. This suggests that larger landholders, with greater resources and assets, are more likely to emerge as opinion leaders within the agricultural community, leveraging their capacity and influence to guide and shape agrarian practices.

CONCLUSION

This research highlights the pivotal role of opinion leaders within agricultural communities, particularly in influencing the dissemination of knowledge and innovations. The opinion leaders are predominantly older, better educated, and possess larger landholdings than the general farmer population. These attributes grant them significant influence within their communities. Leveraging the role of these opinion leaders by extension agencies could significantly enhance the spread of agricultural innovations, as many farmers rely on them for guidance. Extension efforts can be more effective by tapping into these established networks, leading to the broader adoption of new practices and, ultimately, contributing to the development of the entire agricultural community. The findings suggest that targeting opinion leaders in extension strategies is crucial for fostering sustainable agricultural growth and ensuring that innovations reach the grassroots level where they can have the most impact.

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Cultivation of Tomato under Protected Structures: Need of Hour

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***Abstract*:** Current study conducted to investigate the cultivation practices followed by respondents growing tomato under poly house in six district of Punjab. In main season, glut of vegetable arises in the market which lowers down the price. Due to shortage of processing industry and storage infrastructure, off season vegetable is the viable option to enhance the income and quality of produce. The majority of the respondents (57.90 %) sown the tomato crop before the recommended and 21.05 per cent of respondents sown the crop at recommended time. Whereas 21.05 per cent of respondents sown the tomato crop after the recommended time under protected structures. The 68.43 per cent of the respondents grown their own nursery for tomato crop out of which 38.46 per cent grown nursery directly in field and 61.54 per cent used plug trays to grow the nursery. The 31.57 per cent of the respondents did not grown the nursery and purchased the seedlings. The transplanting of the seedling delayed by 26.31 per cent of the respondents whereas 21.05 per cent of the respondents reported early transplanting before the recommended time in tomato capacity.

Keywords: Tomato, Protected structures

India is the second largest producer of vegetables in the world, next to China. Area under vegetable cultivation in India is 9465.30 thousand hectare with production of 168502.90 thousand tonnes and productivity of 17.80 metric tonnes per hectare (Anonymous 2016). In Punjab, area under vegetable cultivation is 208 thousand hectare with production of 4167.60 thousand tonnes and productivity of 15.60 metric tonnes per hectare (Anonymous 2016). To feed the present population of the state, there is a need to double the total production of vegetables. Productivity of vegetables in India is quite low beside it is second largest producer of vegetables. This may be due to high labour requirement in vegetable cultivation, no minimum support price on vegetables has been fixed by govt, glut in main season, poor quality of produce, high cost of seed and no marketing yard near field. Hence, there is need to enhance the production and productivity of vegetable crops through modified strategies to meet the appropriate quantity of vegetables in diet. Olericulturist and extension specialists will have to do some efforts together to achieve the desired level of production potential (George and Singh 2006). Protected cultivation is one of the best technologies to enhance the production, quality and productivity of vegetable crops.

Protected cultivation technology is a technique in which plant microclimate is partially or fully controlled artificially as per the requirement of specific crops to improve the yield potential of crop and to alleviate one or more abiotic stress for optimum growth of crop plants (Satyasai and Viswanathan 1996). In cool season, farmers can raise early crops of better quality with high yield under protected structures to increase their income by following recommended cultivation practices. To ascertain the adoption of recommended cultivation practices in tomato crop, this study has been planned.

MATERIAL AND METHODS

The present study was conducted in Punjab state. Six districts i.e. Amritsar, Gurdaspur, Sangrur, Moga, Jalandhar and Kapurthala were selected purposively. A list of total vegetable growers in selected districts was prepared with the help of department of horticulture. From this list 150 farmers who have adopted protected vegetable cultivation were selected and contacted according to probability proportion of number of farmers doing protected vegetable cultivation in different districts. An interview schedule was designed by consulting relevant literature for data collection. It dealt with the statements to know the cultivation practices followed by the farmers in tomato crop under protected structures. The data were collected personally by the researcher by visiting the study area and interviewing the respondents. For receiving the response of respondents, the investigator contacted them personally in their villages. The data were analyzed with the help of statistical tools such as frequencies, percentage methods.

RESULTS AND DISCUSSION

Sowing practices followed in tomato crop under protected cultivation: Data presented in Table 1 depict that majority of the respondents i.e. 57.90 per cent sown the tomato crop before the recommended time while, 21.05 per cent of respondents sown the crop at recommended time. Whereas 21.05 per cent of respondents sown the tomato crop after the recommended time under protected structures. Similar results were reported by Sharma (2002b) in okra cultivation under open field cultivation.

Data in Table 1 further depicted that 61.54 per cent of respondents used less than recommended seed rate followed by 38.46 per cent sown with more than recommended seed rate of tomato crop. None of the respondent had sown the tomato crop with recommended seed rate under protected structures. Similar results were reported by Khangura and Arneja (2003).

It can be further seen from Table 1 that 68.43 per cent of the respondents grown their own nursery for tomato crop out of which 38.46 per cent grown nursery directly in field and 61.54 per cent used plug trays to grow the nursery. Data further showed that 31.57 per cent of the respondents did not grown the nursery and purchased the seedlings, out of which half of the respondents used recommended number of seedling while remaining half used less than recommended number of seedlings.

To know whether the respondents were maintaining the recommended spacing, respondents were asked about spacing between the plants and rows. The findings of the study revealed that only 15.79 per cent of respondents sown the crop at recommended spacing while, 57.89 per cent of respondents sown tomato at more than recommended spacing while 26.32 per cent of them were sown the crop at less than recommended spacing under protected structures. Similar results were reported by Schreinemachers et al (2016) in tomato crop under protected structures.

Data presented in Table 1 showed that majority of the respondents (69.23%) sown pre treated seeds of tomato crop while 30.77 per cent of them followed seed treatment with recommended chemicals under protected structures. Similar results were reported by Hakim (1998).

Transplanting of the seedling delayed by 26.31 per cent of the respondents and majority of respondents (52.64%) transplanted the tomato under protected structures at recommended time whereas 21.05 per cent of the

Table 1. Distribution of respondents according to sowing practices followed in tomato under protected cultivation

Crop	Sowing practices	Practices followed	Frequency (%)
Tomato	Nursery raising	Yes	102 (68.43)
		No	48 (31.57)
	Method of nursery raising (n=102)	Field	39 (38.46)
		Plug tray	63 (61.54)
	Seed rate (n=102)	Less than recommended (75 g/acre)	63 (61.54)
		Recommended (100g/acre for tomato)	-
		More than recommended (200g/acre)	39 (38.46)
	Seedling rate (n=32)	Less than recommended (8000 seedlings/acre)	16 (50.00)
		Recommended (10000seedlings/acre)	16 (50.00)
	Seed Treatment (n=102)	Treatment done Recommended (Captain or Thiram @ 3 g per Kg or Bavisitin @ 2 g /Kg)	31 (30.77)
		Purchased pre treated seed	71 (69.23)
	Sowing time	Before recommended time (Poly house and Net house: August, Low tunnel: August to September)	88 (57.90)
		Recommended time (Poly house and Net house: Mid September-mid October, Low tunnel: October)	31 (21.05)
		After recommended time (Poly house and Net house: 1st week of November, Low tunnel November)	31 (21.05)
	Spacing	Less than recommended (Plant to Plant 30 cm and Row to Row 40 cm and Bed to Bed 80 cm)	39 (26.32)
		Recommended (Plant to Plant 30 cm and Row to Row 60 cm and Bed to Bed 90 cm)	24 (15.79)
		More than recommended (Plant to Plant 45 cm and Row to Row 45 cm and Bed to Bed 1.6 m)	87 (57.89)
	Transplanting time	Before recommended time (Poly house and Net house: August to end September, Low tunnel: October)	31 (21.05)
		Recommended time (Poly house and Net house: Mid October-mid November (40-45 DAS), Low tunnel: November	80 (52.64)
		After recommended time (Poly house and Net house: 1st week of December, Low tunnel: End December-January)	39 (26.31)

Table 2. Distribution of respondents according to irrigation practices followed under protected cultivation of tomato crop

Irrigation	Category	Tomato (n=150)
		Frequency (%)
Methods of irrigation	Drip	126 (84.21)
	Furrow	24 (15.79)
Irrigation interval	Less than recommended (every day through drip and after 2-3 day through furrow)	63 (42.11)
	Recommended (2 day interval through drip and after 5-7 days through furrow)	87 (57.89)
	More than recommended (3-4 day interval through drip and 8-10 day interval through furrow)	-

Table 3. Distribution of respondents according to time of harvesting under protected cultivation of vegetables

Crop	Time of harvesting	Frequency	Percentage
Tomato (n=150)	Before the recommended time (First week of February, 55-70 DAT)	110	73.68
	At recommended time (Last week of February, 70-80 DAT)	32	21.06
	After recommended time (mid March 85-90 DAT)	8	5.26

respondents reported early transplanting before the recommended time in tomato (Table 1).

Irrigation practices followed under protected cultivation of tomato crop: The data in the Table 2 reveal that majority of the respondent (84.21%) were following drip method of irrigation while 15.79 per cent of them were following furrow irrigation in tomato crops under protected structures. Table 2 further indicated that majority of the respondents (57.89%) were following recommended irrigation interval while 42.11 per cent of respondents were following less than recommended irrigation interval in tomato crop respectively under protected structures.

It can be seen from data in Table 2 that maximum number of respondents adopted drip method of irrigation and apply irrigation at recommended interval under protected cultivation of vegetables.

Time of harvesting for different crops under protected cultivation of vegetables: Data presented in Table 3 indicate that majority of respondents (73.68%) harvested the tomato crop before recommended time while 21.06 per cent of respondents harvested crop at recommended time. Whereas five per cent of respondents harvested the tomato crop after the recommended time of harvesting (Table 3). Tomato crop was harvested before recommended time under protected structures by maximum number of respondents.

CONCLUSION

It can be concluded that under protected cultivation few of respondents sown the crop at recommended spacing while majority of respondents sown tomato at more than recommended spacing while one fourth of them were sown the crop at less than recommended spacing under protected structures. Similar results were reported by Schreinemachers et al (2016) in tomato crop under protected structures. It can also concluded that maximum number of respondents adopted drip method of irrigation and apply irrigation at recommended interval under protected cultivation of vegetables. So, training camps should be organized to train the labourers for successful cultivation of vegetable crops under protected vegetable technologies.

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Seasonal Variations of Floral Biology and Identification of Floral visitors of *Santalum album Linn* in Mid-Hill Zone of Himachal Pradesh

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***Abstract*:** The current study investigates the Seasonal variations of floral biology, and the identification offloral visitors in *Santalum album* within the mid-hill region of Himachal Pradesh. Five phenotypically superior genotypes were selected from fields for two flowering seasons in 2020. The study revealed that S. *album* flowers bloom twice in a year in the same trees but there is variation in flowering intensity, with a moderate level during the season 1 (March- April) period and an intense level during season 2 (August-September) period. Seasonal variations in 2020 significantly influenced bud, inflorescence, flower, and seed morphology. Inflorescence morphological parameters and flower size increased in season 2, indicating favourable reproductive conditions, while bud count and flower numbers were higher in season 1. Fruit and seed traits, such as weight and germination rate, showed higher growth in season 2. Additionally, both seed setting and seed germination percentages was higher in the second season (August to September). Pollen viability decreased with increased storage time and among seasons was maximum for season 2. Floral visitors; black ants (*Lasius nige*r) and Italian honey bees (*Apis mellifera*) were the most frequent and consistent visitors, particularly in the morning. In contrast, blue bottle flies (*Calliphora vomitoria*), dragonflies (*Anisoptera spp.*), and beetles (*Coleoptera spp*) showed lower and more sporadic visit patterns, and beetles were more active during the evening hours.

Keywords: *Santalum album* Linn , Floral biology, mid hills zone, seed setting, floral visitors

The most common and widely accepted fragrant tree, known as the Sandalwood, is a moderately-sized evergreen belonging to the genus *Santalum* in the Santalaceae family. Its primary distribution is in the drier tropical regions of India and the Indonesian islands of Timor and Sumba. (Subasinghe 2022). The first sandalwood survey conducted in India during 1977-78 revealed that sandalwood is distributed throughout the country, with the natural habitats primarily located in the southern part of Karnataka and the northern part of Tamil Nadu. (Rocha et al 2017). It was estimated that approximately 90% of the sandalwood population was in these two states, covering an area of around 8,300km^2. It adapts well to various soil types, including sand, clay, red soils, laterite loam, and even black cotton soils, although it prefers red ferruginous loam with varying fertility However, it does not grow well in waterlogged or icy areas. Trees growing in stony or gravelly soils are known to produce wood with a higher scent (Prasath et al 2019).

Santalum album is a small evergreen tree that reaches a height of 15-20 meters and a girth of up to 2.4 meters, characterized by slender, drooping branchlets. The flowers are small, measuring about 4-6 mm long, and can be purplish-brown, straw-colored, reddish, green, or violet (Garg et al 2016). They appear in small terminal or axillary clusters of up to six and are unscented, arranged in axillary or terminal paniculate cymes that are shorter than the leaves, with floral organs developing in acropetal succession. Floral biology is considered a pillar for systematic, evolutionary, and conservation studies. Understanding the reproductive biology of species, coupled with an analysis of their genetic variation, provides essential data for conservation and various tree improvement programs. This is particularly crucial for endangered species, where limited populations must supply propagules for future generations. Knowledge of floral biology is a prerequisite for both evolutionary and conservation studies (Pullaiah et al 2021).

Flowers of the *Santalum album* are self-incompatible and are specifically adapted for cross-pollination by various flower visitors (Bhasker 1993). This process enhances genetic diversity and ensures the production of viable, high-quality seeds. Effective transfer of pollen through flower visitors between flowers enhances the chances of successful fertilization, resulting in improved seed development and overall reproductive success of the tree (Akbar 2020). The demand for sandalwood is increasing, but forest supplies have nearly ceased, creating a significant gap between demand and availability. Given its vulnerable status and dwindling availability, this species is under threat and requires conservation. Effective conservation and large-scale afforestation efforts hinge on the production of high-quality seeds. To achieve this, it is essential to understand its floral biology. Therefore, there is an urgent need to identify the flower visitors of the *Santalum album*. This study aims to study flower biology and identify effective flower visitors for high-quality seed production of the *Santalum album*.

MATERIAL AND METHODS

The present study was carried out in the field and laboratory of Tree Improvement and Genetic Resources, Dr YSPUHF, Nauni Solan. Five phenotypically superior genotypes were selected from fields for two flowering seasons in 2020. The first flowering season occurs in March to April and the second in August to September. Nine inflorescences were tagged for the study of floral biology. Furthermore, the flower visitor's activity was also observed during the first season (Ghazoul 1997).

Bud and inflorescence morphology: The number of buds, rachis per inflorescence, and flowers per inflorescence were recorded. Lengths and widths of buds and inflorescences were measured.

Flower morphology: Flower length and width were determined. Another length and width, ovary length, and width were measured using the image analyzer.

Fruit and seed morphology: Number of fruits was calculated and fruit diameter (mm) was recorded by digital vernier calliper. Fresh fruit weight (g) and dry seed weight (g) were recorded and seed setting and seed germination percentage were also calculated.

Pollen Studies

Pollen collection: Pollens were collected in isolation to prevent contamination, and then stored in glass vials. These vials were kept in a refrigerator and pollen viability of stored pollens was observed after 30 days.

Pollen viability: Pollen viability of freshly collected as well as previously stored pollens for 30 days from five genotypes was recorded. Pollen viability was assessed using a 2% acetocarmine solution. Freshly dehisced pollen was placed on a clean hemocytometer, and 1 to 2 drops of the acetocarmine solution were added to the pollen mass. This mixture was allowed to settle for 10 to 15 minutes to enable the pollen grains to absorb the stain. Within the five squares of the hemocytometer, pollen grains that were deeply stained and appeared normal were counted as viable, while those that were shrivelled and weakly stained were categorized as non-viable (Monga 2021).

Floral visitor's visit: Floral visitors' visit and their activities were observed during season 2 of 2020. The pollination dynamics of the primary pollinators were observed twice daily: during the morning from 9-11 am and in the evening from 5-7 pm at the time of flowering and the photograph was used to identification of each flower visitor (Talwar and Bhatnagar 2014).Insect visiting time was recorded in the morning and evening with the help of a stopwatch.

Statistical analysis: Data analysis was done through R software and graphs were also generated with R studio (Posit team 2024).

RESULTS AND DISCUSSION

Bud and inflorescence morphology: The morphology of bud and inflorescence across two distinct seasons in 2020 revealed several notable variations. The inflorescence length showed a slight seasonal increase, ranging from 7.00-7.77 cm in season 1 to 7.12-7.99 cm in season 2. Similarly, the inflorescence width expanded from 3.13-4.12 cm in season 1 to 3.26-4.54 cm in season 2. The number of rachises per inflorescence remained relatively consistent, ranging from 6.69-7.78 in season 1 and showing a minor increase to 7.34-7.58 in season 2. The reduction in the number of flowers per inflorescence was observed, with counts decreasing from 49.00-56 in season 1 to 40.79-45.00 in season 2. Bud parameters also varied between seasons; the bud count per inflorescence was higher in season 1, ranging from 77.7-88.9, while in season 2, it was 74.35-77.45. Bud length exhibited a slight decline from 0.67-0.72 cm in Season 1 to 0.56-0.67 cm in Season 2, though bud width remained fairly stable across both seasons, ranging from 0.33-0.45 cm in season 1 and 0.3-0.45 cm in season 2 (Table 1). Krishnakumar and Parthiban (2017) also reported that morphological parameters of buds and inflorescence were maximum in season 2 as compared to season 1.

Flower morphology: Flower length increased from 0.33-0.49 cm in season 1 to 0.43-0.57 cm in season 2, while flower width also increased from 0.65-0.77 cm to 0.78-0.89 cm. The number of fruits was maximum in season 1 ranging from 8.23- 12.00 and 11.22-18.78 in season 2. Fruit diameter increased from 8.17-9.22 mm to 9.56-9.95 mm, and fresh fruit weight increased from 1.45-2.12 g to 1.95-2.89 g. Anther length ranged from 0.43-0.50 mm in season 1 and increased to 0.44-0.53 mm in season 2. Anther width ranged from 0.65-0.69 mm in season 1 and from 0.60-0.67 mm in season 2 (Table 1). However, the decrease in anther width suggests that not all parameters are uniformly affected by seasonal changes. Ovary length and width both showed similar patterns of slight seasonal variation. The observed seasonal increases in flower length, flower width, and ovary width indicate that external environmental conditions may favor reproductive growth during the second season, highlighting the dynamic nature of plant development (Ratnaningrum et al 2017, Krishanakumar and Partiban 2017). Seasonal variability of floral traits may be useful for understanding plant reproductive strategies.

Seed morphology: The number of fruits increased from Season 1, with a range of 8.23-12.00, to season 2 (11.22-18.78 fruits). Fruit diameter also showed an increase, from 8.17-9.22 mm in season 1 to 9.56-9.95 mm in season 2, and fresh fruit weight followed this trend, increasing from 1.45-2.12 to 1.95-2.89 g. In terms of seed morphology, the seed diameter ranged from 6.12-6.78 mm in season 1 and slightly varied to 5.99-7.11 mm in season 2, while dry seed weight showed greater variability between the seasons, ranged between 0.13-0.22 g in season 1 to 0.11-0.32 g in season 2. Seed setting percentage increased from 16.14-23.08% in season 1 to 27.52-43.00% in season 2. Seed germination percentage (%) also increased from 45.88-55.3% in Season 1 to 56.78-73.12% in Season 2. Seed and seedling traits play a crucial role in determining plant fitness and long-term survival, with these traits being shaped by the dynamic interaction between the plant and its surrounding environment (Saini et al 2022, Madhuvanti et al 2024). The high fruit set rate observed during the August-September flowering season can be attributed to the nutrient-rich soil conditions resulting from the occurrence of rains.

Pollen studies: Storage time affects the pollen viability of the *Santalum album*. Freshly collected pollens were more viable as compared to stored pollen for 30 days. Pollen viability showed a decreasing trend with increasing time (Fig. 1). Pollens of season 2 were more viable than season 1. In season 1, maximum viability of freshly collected pollens was for T_3 (86.15%) followed by T_5 and T_1 whereas for stored pollens pollen viability follows the trend viz., T_3 (81.15%) followed by T_1, T_5. The maximum pollen viability was for T3 (87.98%) followed by T_1T_2. T_4whereas for stored pollens pollen viability was T_3(79.63%) followed by $T_5$and T_1(Fig. 1).

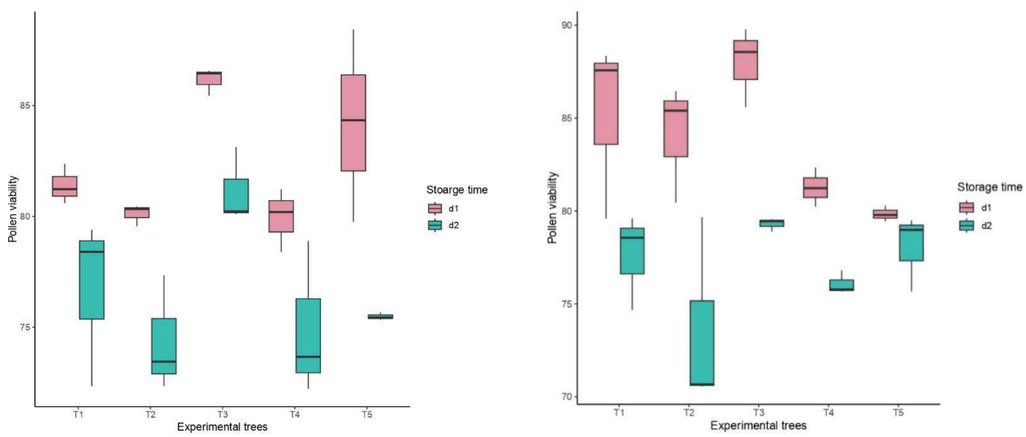

Fig. 1. Effect on storage duration (days) on pollen viability (%) of *Santalum album* Linn (A) Season 1 and (B) Season 2

Table 1. Morphological variations in buds, inflorescence, flowers, fruits and seeds of *Santalum album*

Parameters	2020 (Season 1)	2020 (Season 2)	Parameters	2020 (Season 1)	2020 (Season 2)	Parameters	2020 (Season 1)	2020 (Season 2)
Morphological variations of bud and inflorescence			Morphological variations of flowers			Morphological Variation of Fruit and Seed		
Inflorescence length (cm)	7.00-7.77	7.12-7.99	Flower length (cm)	0.33-0.49	0.43-0.57	No of fruits	8.23-12.00	11.22-18.78
Inflorescence width (cm)	3.13-4.12	3.26-4.54	Flower width (cm)	0.65-0.77	0.78-0.89	Fruit diameter (mm)	8.17-9.22	9.56-9.95
No. rachis/ inflorescence	6.69-7.78	7.34-7.58	Anther length (mm)	0.43-0.50	0.44-0.53	Fresh fruit weight (g)	1.45-2.12	1.95-2.89
No. of flower /inflorescence	49.00-56	40.79-45.00	Anther width (mm)	0.65-0.69	0.60-0.67	Seed diameter(mm)	6.12-6.78	5.99-7.11
No. of bud	77.7-88.9	74.35-77.45	Ovary length (mm)	1.29-1.46	1.33-1.40	Dry Seed weight (g)	0.13-0.22	0.11-0.32
Bud length (cm)	0.67-0.72	0.56-0.67	Ovary width (mm)	0.60-0.66	0.70-0.77	Seed setting percentage (%)	16.14-23.08	27.52-43.00
Bud width (cm)	0.33-0.45	0.3-0.45	-	-	-	Seed germination percentage (%)	45.88-55.3	56.78-73.12

Pollen visitors: Black ants (*Lasius nige*r) and Italian honey bees (*Apis mellifera*) were the most frequent and consistent flower visitors with 80 % and 100 % of their visit, particularly in the morning. In contrast, blue bottle flies (*Calliphora vomitoria*), dragonflies (*Anisoptera* spp.) and beetles (*Coleoptera* spp) showed lower and more sporadic visitation patterns with 40, 30 and 10% flower visit and beetles being more active during the evening with 20% of visit (Table 2). Hareesha et al (2022) alsoobserved that ants and bees are the primary pollinators in *Santalum album*.

Time spent on flower: Black ants were consistent visitors across most days, spending between 5 and 30 seconds on flowers. The highest was on day 8 (20-30 seconds), while the shortest was on day 1 (5-20 seconds). Black ants did not visit the flowers on Day 3. Italian honey bees visited flowers each day, spending between 0 and 30 seconds. The longest time was observed on day 8 (20-30 seconds), while the shortest was on day 7 (0-15 seconds). These flies were observed on six days, with a duration range of 5-20 seconds. The highest time spent was on days 1 and 2 (10-20 seconds), and t did not appear on 4, 5, 6, 7, 9, and 10 day. Dragonflies were observed for three days only, with times ranging from 0 to 15 seconds longest on flowers on day 9 (10-15 seconds) and the least on day 2 (0-5 seconds). Beetles visited on three occasions (2, 8,

Table 2. Pollinators visiting time in *Santalum album* Linn.

Visiting days	Pollen vectors									
	Black ant		Italian honey bee		Blue bottle fly		Dragon fly		Beetle	
	Morning (9 am- 11am)	Evening (5 pm - 7pm)	Morning (9 am - 11am)	Evening (5 pm - 7pm)	Morning (9 am - 11am)	Evening (9 am - 11am)	Morning (9 am - 11am)	Evening (5 pm - 7pm)	Morning (9 am - 11am)	Evening (5 pm - 7pm)
Day1	√	-	√	-	√	-	√	-	-	
Day2	√	-	√	-	√	-	√	-	√	
Day3	-	-	√	-	√	-	-	-	-	
Day4	√	-	√	-	-	-	-	-	-	
Day5	√	-	√	-	-	-	-	-	-	
Day6	√	-	√	-	-	-	-	-	-	
Day7	√	-	√	-	-	-	-	-	-	
Day8	√	-	√	-	√	-	-	-	-	√
Day9	√	-	√	-	-	-	√	-	-	√
Day10	√	√	√	-	-	-	-	-	-	
Morning (%)	80		100		40		30		10	
Evening (%)	10		-		-		-		20	
No visit (%)	10		100		60		70		70	

Table 3. Variation for pollinators' time spent / flower in *Santalum album* L. at different days of flowering

Day fatter flowering	Pollinators' time spent on flowers (seconds)				
	*Lasiusnige*r (Black ants)	*Apis mellifera* (Italian honey bees)	*Calliphora vomitoria* (Blue bottle fly)	*Anisoptera spp.* (Dragonfly)	*Coleoptera spp* (Beetal)
1	5-20	10-20	10-20	5-10	-
2	15-20	5-15	5-10	0-5	30-40
3	-	10-15	10 -15	-	-
4	10-15	15-20	-	-	-
5	15-25	10-15	-	-	-
6	10- 20	5-15	-	-	-
7	15-20	0-15	-	-	-
8	20-30	20-30	5-15	-	25-35
9	15-20	5-20	-	10-15	25-40
10	5-15	10-20	-	-	-

and 9). They spent the most time on flowers compared to other pollinators, with a duration range of 25-40 seconds. Their longest time spent was on day 9 (25-40 seconds) (Table 3). Some pollinators like black ants and Italian honey bees visit more consistently, while others like dragonflies and beetles visit less frequently but spend longer durations on certain days (Baskorowati 2011, Krishnakumar et al 2018).

CONCLUSIONS

The seasonal variations in 2020 markedly affected bud, inflorescence, flower, and seed morphology. Season two displayed enhanced reproductive success, as evidenced by increased inflorescence size, flower dimensions, and improved fruit and seed traits, including weight and germination rate. Seed setting and germination percentages were highest in season two. These findings suggest that season two (August to September) provided optimal conditions for floral, fruit, and seed development, underscoring its significance for future reproductive and morphological studies. Black ants (*Lasius niger*) and Italian honey bees (*Apis mellifera*) were observed as the most frequent and consistent visitors, particularly in the morning hours, suggesting their role as primary pollinators. In contrast, blue bottle flies (*Calliphora vomitoria*), dragonflies (*Anisoptera* spp.), and beetles (*Coleoptera* spp.) demonstrated lower and more sporadic visitation rates, with beetles exhibiting peak activity in the evening.

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