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Impact of Adoption of High Yielding Varieties of Paddy at Adhaura Block in Kaimur District of Bihar

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Abstract

A case study was conducted to know the changes (impacts) in adoption of improved and hybrid varieties with other components of paddy over traditional varieties among farmers at different villages of Adhaura block in Kaimur district (Bihar) in the year 2019. 75 benefitted farmers from 6 villages were selected randomly who were trained and demonstrated by Krishi Vigyan Kendra for adoption of improved varieties under program groups and 125 non-benefitted farmers were also selected from 5 villages under non-program groups. We found that hybrid varieties had given higher yield and income followed by improved varieties over traditional in both the program and non-program groups. 59.88 per cent paddy area was covered by hybrid among sampled farmers under program groups and 71.86 per cent area was covered by non-program groups in the assessment year 2019. Hybrid varieties of paddy were promoted by Govt. of Bihar with subsidies as well as private seed dealers without subsidy.

Keywords : *Adoption, Responsible Factors for Adoption, Parameters for Impact Assessment*

Introduction

A team of Krishi Vigyan Kendra (KVK) scientists surveyed many villages and farmers of tribal dominated block named Adhaura in Kaimur district of Bihar and analysed their data to find out the technological gaps regarding crops and others enterprises from time to time. 14 villages and 354 farmers were surveyed from the year 2008 t0 2010. After analysis of paddy crop we found that maximum farmers were growing short duration and traditional varieties with low productivity for long years. Mainly grown varieties were Saro, Serha,Barwa, Sukhdas and Lalorh in plateau region with rainfed situation. Yield of varieties varied from 22qtls to 24qtls in different locations due to their low yield potentiality, use of imbalance doze of fertilizers and lack of plant protection chemicals etc. Low yield of paddy was the main problem. They produced paddy to meet their demand for food for seven to eight months only and therefore almost the members of farm family migrated seasonally to plain area (canal belt) to engage themselves in harvesting, threshing and winnowing of paddy as per demand by large farmers for two months from mid November to mid January. They earned 2-3 qtls paddy per head as wage and thus they maintained their four months food demand. We thought that there was a need to replace old and traditional paddy varieties by improved varieties for enhancing yield in the rainfed area. KVK intervened and decided to conduct first of all 'On Farm Trial' to test the performance of high yielding and short duration varieties of paddy with local check and on the basis of OFTs' result best varieties were demonstrated in large area in different villages of Adhaura block. Some improved varieties of paddy were tested under OFTs in different years and based on OFTs results best varieties – MTU-1010, Abhishek and Sabour Harshit were given under Front Line Demonstrations (FLDs). OFTs were conducted at Bharehara village in 2015, Mundehara in 2016 and Karar village in 2017 and FLDs were conducted at Londa village in 2016, Bahadag in 2017 and Dugha village in 2018.

Trainings related to package of practices for paddy production were also conducted from time to time in adopted villages. In addition to KVK, other agencies like Govt. of Bihar and other private seed companies were also involved to replace farmers' varieties of paddy with subsidized and without subsidized rate since the year 2010 and onwards. Some hybrid and improved paddy varieties were also supplied by Govt. and private dealers. Our objectives were to find out the impact of overall given technology (paddy improved varieties) through OFTs and FLDs in different years by KVK as well as hybrid varieties supplied by others agencies including farmers practice. Impact will include yield, income, cost, adoption percentage and area expansion as main indicators with some others indicators. Data regarding paddy varieties wise (traditional, improved and hybrid), yield, income, cost and area expansion will be compared between base year 2010 and assessed year 2019 in both cases adopted and non-adopted villages. Therefore we conducted a case study in the year 2019 to achieve the objectives regarding changes due to adoption of new technologies.

Data Sources and Methodology

In the first step, six villages – Londa, Dugha, Bahadag, Bharehara , Mundehara and Karar were selected purposively under program groups because 113 farmers had been surveyed in those villages up to 2010 in which OFTs and FLDs had been conducted in different years. In the second step, parts from programmed villages, 241 farmers in eight villages were also surveyed by Krishi Vigyan Kendra in the same years. Out of eight non-program villages five villages – Panchmahul, Lohra, Barap, Jamuninar and Gamharia were selected randomly. In the third step, five farmers who were paddy growers, from each three programmed villages - Bharehara , Mundehara and Karar where OFTs programmes had been conducted, were selected randomly and twenty farmers (paddy growers) of each three programmed villages - Londa, Dugha and Bahadag where FLDs had been conducted, were selected randomly. In the fourth step, twenty five farmers of each five villages under non-program groups and who were paddy growers, were randomly selected. In the fifth step and finally 11 villages and 200 farmers were selected in which 15 farmers were related to OFTs and 60 farmers were related to FLDs under program groups and 125 farmers were belonged to non-program groups. Thus 200 farmers were selected randomly for detailed investigation for impact assessment. Survey method was group interview by pre tested schedules and personal contact.

Results and Discussion

It covered the adoption new varieties of paddy and its impact after adoption. Improved and hybrid varieties had played a vital role to enhance the yield, income and area over traditional varieties of paddy in rainfed situation of Adhaura block. Table revealed that out of surveyed 6 villages and 113 famers in the base year 2010, 75 sampled farmers of the same 6 villages under program group(under OFTs and FLDs) were found that 23 farmers (30.67%) had adopted improved varieties - MTU-1010, Abhishek, Sabour harshit and Aman as well as 48 farmers(63.99%) had adopted hybrid paddy varieties – 6444, 5251 and Shankar sudha etc. whereas only 5 farmers(5.34%) were using traditional varieties with improved and hybrid in the assessment year 2019. Earlier in the 2010, out of 113 farmers 103(91.15%) farmers were using traditional varieties and rest only 10 farmers (8.85%) were cultivating improved and hybrid varieties. In non-program villages , out of 241 surveyed farmers in 8 villages only 30 famers(12.45%) were using improved and hybrid varieties in the year 2010 had been shifted 116(92.80%) sampled farmers for improved and hybrid varieties in 5 sampled villages among 125 sampled farmers in the assessment year 2019. Only 9 (7.20%) sampled farmers were in practice for traditional varieties with hybrid. Out of 101.25ha area of 113 farmers was covered with 91.95ha(90.81%) for traditional varieties in the base year 2010 but in the assessment year 2019 only 3.60ha(4.64%) area was found under traditional varieties in sampled 77.50ha among 75 farmers and balance area 73.90ha area was engaged by improved and hybrid paddy varieties in program groups. Similarly in non-program groups, out of total 131.32ha sampled area, 131.32ha(95.39%) was used for improved and hybrid in the assessment year as compared to 28.70ha(14.12%) in total area 203.20ha in the base year 2010. Per farmer's area in 2010 was found between 0.90ha and 0.84ha in program and non-program groups respectively but area was expanded in the year 2019 between 1.04ha(115.56%) and 1.10ha(131.00%) in program and non-program groups

TABLE : Different indicators for impact assessment between base and assessment year

S. No	Base year – 2010 Indicators	Assessment year - 2019 Program group		Non-program group	
		2010	**2019**	**2010**	**2019**
1	Surveyed villages	06	06	08	05
2	Sampled farmers	113 (100.00)*	75 (100.00)	241 (100.00)	125 (100.00)
3	No. of users of traditional varieties - Serha, Saro, Barwa, Sukhdas and Lalorh users	103 (91.15)	4 (5.34)	211 (87.55)	9 (7.20)
	Improved varieties users (nos.) – MTU-1010, Abhishek, Sabour harshit and Aman and others	08 (7.08)	23 (30.67)	25 (10.37)	27 (21.60)
	Hybrid varieties users (nos.) – 6444, 5251, Shankar Sudha and others	02 (1.77)	48 (63.99)	05 (2.08)	89 (71.20)
5	Area (ha)	101.25 (100.00)	77.50 (100.00)	203.20 (100.00)	137.67 (100.00)
	Traditional varieties users	91.95 (90.81)	3.60 (4.64)	174.50 (85.88)	6.35 (4.61)
	Improved varieties users	8.00 (7.90)	27.50 (35.48)	19.75 (9.72)	32.40 (23.53)
	Hybrid varieties users	1.30 (1.29)	46.40 (59.88)	8.95 (4.40)	61.25 (71.86)
6	Per farmer's area expansion (ha)	0.90	1.04 (15.56)	0.84	1.10 (31.00)
7	Yield (qtl/ha) and increase(%) over traditional				
	Traditional varieties users	23.60	25.70	23.88	24.68
	Improved varieties users	28.75(21.82)	37.80(47.08)	27.20(13.90)	35.00(41.82)
	Hybrid varieties users	31.20(32.20)	41.85(62.84)	30.10(26.05)	40.55(64.30)
8	Income (Rs.)/ha and increase(%) over traditional				
	Traditional varieties users	28320	39835	28656	38254
	Improved varieties users	34500 (21.82)	58590 (47.08)	32640 (13.90)	54250 (41.82)
	Hybrid varieties users	37440 (32.20)	64867 (62.84)	36120 (26.05)	62852 (64.30)
9	Cost (Rs.)/ha and increase(%) over traditional				
	Traditional varieties users	16090	22008	16856	21735
	Improved varieties users	18649(15.90)	27251(23.82)	18235(8.18)	26335(21.64)
	Hybrid varieties users	19398(20.56)	29352(33.37)	19213(13.98)	29508(35.76)
10	BC ratio				
	Traditional varieties users	1.76	1.81	1.70	1.76
	Improved varieties users	1.85	2.15	1.79	2.06
	Hybrid varieties users	1.93	2.21	1.88	2.13
11	Seasonal migration of sampled households	61 (53.67)	23 (30.00)	136 (56.43)	40 (32.00)

Source:- Field survey *Figures in parenthesis show percentage respectively. Chaudhary Rambalak (2016) had also found in their sample study that area of rice was expanded from 0.82 ha(year 2009-10) to 0.85ha(2010-11) in which coverage of HYVs and Hybrids were 86.58 per cent and 13.42 per cent respectively in the year 2009-10 but in 2010-11, Hybrids covered 17.64 per cent and remaining 82.36 percent was covered by HYVs. The most important parameter that was yield were found in increasing position due to impact of training, demonstrations, on farm trials, awareness and others factors conducted by KVK and Govt. as well as private agencies and stakeholders. Table indicated that in the base year Yield, Income, Cost of cultivation and Cost Benefit Ratio(BCR) were found 23.60qtl/ha, Rs.28320, Rs.16090 and 1.76 respectively under program groups for traditional varieties whereas Yield, Income, Cost of cultivation and Cost Benefit Ratio(BCR) were analysed 23.88qtl/ha, Rs.28656, Rs.16856 and 1.70 respectively in non-program groups from traditional varieties. In assessment year 2019 yield, income, cost of cultivation and BCR were increased by using traditional varieties and that were found 25.70qtl/ha, Rs.39835, Rs.22008 and 1.81respectively in program groups. Similarly increasing trends were found in non-program groups also over base year 2010. Adoption of use of fertilizers, plant protection chemicals and irrigation were main causes to increase the yield and other performance indicators from base year to assessment year in the both program and non-program groups for traditional varieties. Those causes were observed in the cases of improved and hybrid varieties also as depicted in table. Under program groups, per hectare yield, income and cost from improved varieties were increased over traditional varieties and that were found 28.31qtl/ha(21.82%), Rs.34500(21.82%) and Rs.18649(15.90%) respectively in base year 2010 but it was shifted to yield 37.80qtl/ha(47.08%), Income Rs.58590(47.08%) and cost Rs.27251(23.82%) in sampled farmers in the assessment year 2019. Table revealed that hybrid varieties performed better than improved varieties in yield, income and BCR in both program and non-program groups due to their yielding capacities. 32.20 per cent (31.20qtl/ha) yield was increased by hybrids over traditional in 2010 under program groups whereas by the same sampled groups in 2019, hybrids gave 62.84 per cent extra yield(41.85qtl/ha) over traditional varieties(25.70qtl/ha). In non-program groups, additional 26.05 per cent yield(31.10qtl/ha) was achieved by hybrids over traditional yield(23.88qtl/ha) as well as 10.66 per cent extra yield over improved yield(27.20qtl/ha) in 2010 but the same groups under samples in 2019, hybrids gave 64.30 per cent and 15.86 per cent more yield than traditional and improved respectively. Table indicated that in both groups(program and non-program) and in both years(2010 and 2019) improved varieties achieved better yield and income over traditional varieties but lesser than hybrids. Based on both groups and years, additional yield and income were achieved between 27.20 per cent and 47.08 per cent by improved varieties over traditional varieties. Seasonal migration among households had come down from 53.67 per cent in 2010 to 30.00 per cent in 2019 under program groups and similarly from 56.43 per cent to 32.00 per cent under non-program groups due to production of food grains mainly paddy (Rice) for every year in their land by adoption and diffusion of new technologies like improved and hybrid varieties, balance doze of fertilizers, plant protection, irrigation etc.

Conclusion and Policy Implications

Impact of OFTs and FLDs by KVK was positive for adoption of improved varieties(MTU-1010, Abhishek and Sabour harshit) of paddy by sampled farmers because sampled farmers had increased their yield and income per ha 47.08 per cent, area expansion 15.56 per cent although per ha cost were also increased 23.82 per cent over traditional varieties like - Serha, Saro, Barwa, Sukhdas and Lalorh in program groups for the assessment year 2019. Aman variety was also popular which was spread by private seed company. In non-program groups also 21.60 per cent farmer had adopted improved varieties which were demonstrated by KVK due to diffusion by beneficiaries through seed exchange, seed sale. Others extension agents like neighbours, relatives, friends, Govt. and private seed dealers etc. Hybrid varieties performed better than improved varieties in yield, income and BCR in the both program and non-program groups in the both years also base and assessment due to their higher yielding capacities which were promoted by Govt. with subsidy and private agencies without subsidy. 59.88 per cent paddy area was covered by hybrid among sampled farmers under program groups and 71.86 per cent area was covered by non-program groups in the assessment year 2019. Government must encourage small and marginal farmers for adoption of HYV and hybrid rice, to popularize the same, rice minikits(mainly hybrids kits) must be distributed at a larger scale in rainfed situation.

Recommendations

Hybrid varieties of paddy were recommended for farmers followed by improved varieties due to their higher yielding capacity to fulfill their food security and income. Those varieties were short and medium duration as well as rainfed suitable for Adhaura block in Kaimur district of Bihar.

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Impact of Salinity Stress on Protein Regulation in Rice Seedlings (*Oryza sativa* L.)

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Abstract

Climate change and soil salinity pose significant threats to global food security, with salinity affecting approximately 1,125 million hectares worldwide, including 20% of cultivated and 33% of irrigated lands. Rice, a staple food for millions, is highly susceptible to salinity stress, which disrupts water uptake, induces ion toxicity, and impairs essential metabolic processes. This study investigates the impact of salinity stress on rice seedlings, focusing on biochemical changes, particularly protein content and synthesis. Results indicate that salinity stress reduces overall protein levels due to inhibited ribosomal activity while upregulating specific stress-responsive proteins that enhance adaptation. These molecular responses play a crucial role in plant defense mechanisms, enabling osmotic adjustment, ion homeostasis, and oxidative stress mitigation. Genotypes such as Pokkali, Nona Bokra, SR26B, Kalabet, Kalavat, Gosabaexhibit superior protein responses under salinity, suggesting their potential for breeding salt-tolerant rice varieties. Understanding these stress-induced changes is essential for developing strategies to enhance resilience, improve productivity, and ensure sustainable agriculture in the face of increasing environmental challenges.

Keywords : Rice seedlings, salinity stress-responsive proteins,oxidative stress,metabolic adaptation, crop resilience

Introduction

Climate change and food security are critical challenges of the 21st century, with the global population projected to reach 9 billion by 2050, increasing food demand by 85% (FAO, 2017). Agriculture is increasingly affected by drought, extreme temperatures, and soil salinity, particularly in arid and semi-arid regions. Currently, about 1,125 million hectares worldwide are salt-affected, including 20% of cultivated and 33% of irrigated lands (Kumar and Sharma, 2020). Major affected countries include India, China, the U.S., Australia, and several others (Hasanuzzaman, 2014). In India, approximately 6.74 million hectares, or 2.1% of the country's land, are salt-affected, with Gujarat, Uttar Pradesh, Maharashtra, West Bengal, and Rajasthan being the most impacted states (Mandal et al., 2018). Alarmingly, salinization is increasing by 10% annually, and by 2050, nearly half of all arable land may be affected.

Soil salinity significantly reduces agricultural productivity by impairing plant development from germination to maturity. High salinity disrupts water absorption, induces nutrient imbalances, and leads to Na^+ and Cl^- toxicity, limiting essential nutrients like K, N, P, Ca, and Fe (Hauser and Horie, 2010). The imbalance negatively affects enzymatic activities crucial for photosynthesis and protein synthesis, ultimately reducing crop yields and economic returns. Addressing soil salinity is essential for sustainable agriculture and global food security.Rice is a globally important crop, covering 156 million hectares and yielding 650 million tons annually. India, the largest cultivator (44.6 million hectares) and second-largest producer after China, contributes 21% to global rice production (FAO, 2008). Asia dominates rice production, with China, India, and Pakistan leading (Khush, 2005; Calpe, 2006). India is also the top exporter of Basmati rice, with key production areas in Jammu & Kashmir, Himachal

Pradesh, Punjab, Haryana, Uttarakhand, and Western Uttar Pradesh (Udhayakumar & Karunakaran, 2020).

Rice production is highly vulnerable to abiotic and biotic stresses, especially salinity, which is exacerbated by population growth, freshwater scarcity, and environmental changes (Shahbaz & Ashraf, 2013). Salinity stress imposes osmotic and ionic imbalances, leading to water deficits, stomatal closure, reduced photosynthesis, and nutrient depletion (Awais *et al.*, 2023; Mendes *et al.*, 2024).Salinitystress causes; membrane damage, decreases photosynthetic rate, chlorophyll fluorescence traits, changes leaf water potential, relative water content, increases ROS level, and modifies antioxidant enzymes production system. Intensity of the membrane deterioration processes are proportional to ionic concentrations (Djanaguiraman, M., Prasad2013). Excess sodium (Naz) accumulation disrupts potassium (Kz) and other essential nutrients, potentially causing premature leaf senescence and plant death (Munns & Tester, 2008). Salinity negatively impacts rice by inhibiting germination, reducing leaf area, delaying seed set, and causing sterility, ultimately leading to yield losses (Zeng *et al.*, 2003). It affects seedling growth, tillering, and spikelet formation, further compromising productivity. To combat salt stress, plants employ osmotic adjustment by accumulating inorganic ions, sugars, amino acids, and quaternary ammonium compounds. Additionally, salinity-induced oxidative stress disrupts photosynthesis, prompting protective mechanisms such asxanthophyll cycling and alternative electron transfer pathways. Plants upregulate antioxidant enzymes like superoxide dismutase, ascorbate peroxidase, and catalase to mitigate reactive oxygen species (ROS)-induced damage (Mohammadi, 2013).

Saline groundwater, climate change-induced evaporation, and deforestation further exacerbate the issue. These factors collectively degrade soil quality, impacting agriculture and ecosystems.

This study aims to understand how salinity stress affects the early growth stages of rice seedlings bybiochemical changes. The study investigates changes in protein content and synthesis, as salinity stress can interfere with essential metabolic processes, reducing the production of vital proteins necessary for plant development. By examining these factors, researchers can gain a better understanding of how rice seedlings respond to saline conditions and identify potential strategies for improving salinity tolerance.

Materials and Methods

Plant materials and salinity stress

A total number of 32 type rice variety (Table 1) were collected from the germplasm collection at department of genetics and plant breeding, university of Calcutta for the present study. Here, two different salinity levels (6 EC, 12 EC) were used in the form of NaCl solution for imposing the salinity stress. The control treatment was without salts.To prepare the salt-stressed medium, 1 litre of distilled water is measured, and the required amount of sodium chloride (NaCl) is added to achieve salinity levels of 6 EC (60 mM NaCl) and 12 EC (120 mM NaCl). For seed germination a layer of blotting paper is placed in each Petri dish, and 100 seeds are evenly distributed on the paper. The filter paper is then moistened with the respective saline solution, ensuring it remains wet but not waterlogged. The Petri dishes are covered with lids to prevent evaporation and placed in a BOD incubator at 25–30°C. After 14 days, protein is estimated by using Lowry's method in control, 6EC and 12EC to assess the biochemical impact of salinity stress on rice seedlings.

Biochemical Analysis

Protein estimation by Lowry's method

The Lowry's method (Lowry, O. H., Rosebrough1951) for protein estimationdescribed by Sadasivam and Manickam (1996) involves the Biuret reaction and Folin-Ciocalteu reagent, forming a blue complex measurable at 660 nm. A BSA stock solution is diluted to prepare a working standard. Protein extraction is done using a HEPES-based buffer, followed by filtration and centrifugation. For estimation, the sample or standard is mixed with Alkaline Copper Reagent, incubated, and then treated with Folin-Ciocalteu reagent. After a final incubation in the dark, absorbance is measured at 660 nm, and protein concentration is determined using a standard curve.

TABLE 1. Description of Rice germplasm under study

Serial no	Variety name	Grain colour
1	Pokkali	White
2	Bhootnath	White
3	NonaBokhra	White
4	SR26B	White
5	kanak	White
6	kaknishal	White
7	Boby	White
8	Gitanjali	White
9	Kaushallya	White
10	Kanakchur	White
11	Pratiksha	White
12	Bahurupi	White
13	Kabirajshal	White
14	Jalkamini	White
15	Jugol	White
16	Kalabati	Black
17	Lathishal	White
18	Thubi	White
19	Jhumpuri	White
20	Kalavat	White
21	Manipuri red	White
22	Kalabet	Black
23	Indorama	Black
24	Harinkojli	Red
25	Marishal	Red
26	Dudhshal	White
27	Dumra	White
28	Swarna Sub 1	Red
29	Gosaba	Brown
30	Basudev	Brown

Results and Discussion

Protein assay

proteins in rice seedlings play a crucial role in adapting to salinity stress by regulating ion homeostasis, synthesizing osmolytes, and stabilizing cellular structures. Stress proteins refold damaged proteins, while antioxidant enzymes detoxify reactive oxygen species. Proteins modulate gene expression through signal transduction and transcription factors, optimize energy metabolism, and regulate hormonal signaling to enhance root growth. Additionally, pathogenesis-related proteins strengthen the plant's immune defense against opportunistic pathogens. Amount of protein present in 32 different genotypes were evaluated based on standard deviation and theirs mean value. The result (Table no 2) demonstrare variability among the varieties, highlighting their potential for breeding programs aimed at enhancing salinity stress tolerant varieties.

The analysis of protein content on different salt stress revealed significant variability among rice varieties studied.The amount of protein in percentage in control ranged from a low 2.27 in Kaknishal to a remarkable 3.35 in Gitanjali, with selected checks for salt tolerant pokkali (2.63) and salt susceptible Bhootnath. In salt stress 6EC the value ranged from a low 1.54 in Bahurupi to 2.91 in gitanjali where as in check variety Pokkali it is 2.12 and in Bhootnath it is 1.38. In case of higher salt stress means 12EC lowest amount is 1.10 in Kanak, Jhumpuri and Harinkojli and in Gitanjali and Kalavat it is 2.69. When rice seedling raised under salinity stress significant change in protein content could be observed in shoots. Protein content decreasedunder different salt stress(12EC and 6 EC). Rice variety like Pokkali, NonaBokra, SER6B, Kalabet, Kalavat, Gosaba, Basudha, Gitanjali shows less decrease of protein than the variety like Bhootnath, Jalkamini, Jhumpuri, Marishal, Kaknishal. The less descend value of protein between control and 12EC means those varieties are better in salt tolerance and the higher difference between control and 12EC means varieties are more salt susceptible than others.

From the graphical representation (fig no1) found that the lowest standard deviation (0.41) in Basudha and the highest standarddeviation(0.81) inKaushyallya in refecrence of checks which are 0.49 in Pokkali and 0.89 in Bhootnath. Instatistics, the standard deviationisa measure of the amount of variation of the values of a variable about its mean. A low standard deviation indicates that the values tend to be close to the mean (also called the expected value) of the set, while a high standard deviation indicates that the values are spread out over a wider range.

Conclusion

Salinity stress alters protein levels in rice seedlings, reducing overall content due to inhibited ribosomal activity while upregulating stress-responsive proteins that aid adaptation. Understanding these changes is crucial for developing salt-tolerant crops. By manipulating protein expression, plant resilience and productivity can be improved, mitigating stress effects. Further research is needed to explore the molecular mechanisms regulating protein and sugar metabolism under stress. Advancing knowledge in this area will help develop strategies for enhancing stress tolerance, ensuring agricultural sustainability, and improving global food security in the face of increasing environmental challenges. Notably genotypes like Pokkali, NonaBokra, SR6B, Kalabet, Kalavat,Gosaba, Basudha, Gitanjali preferably shows desirable characteristics in relation to protein content with salt stress which suggesting that these varieties are potent to be used as a salt tolerant line in a breeding programmed than the varieties like Bhootnath, Jalkamini, Jhumpuri, Marishal, Kaknishal.

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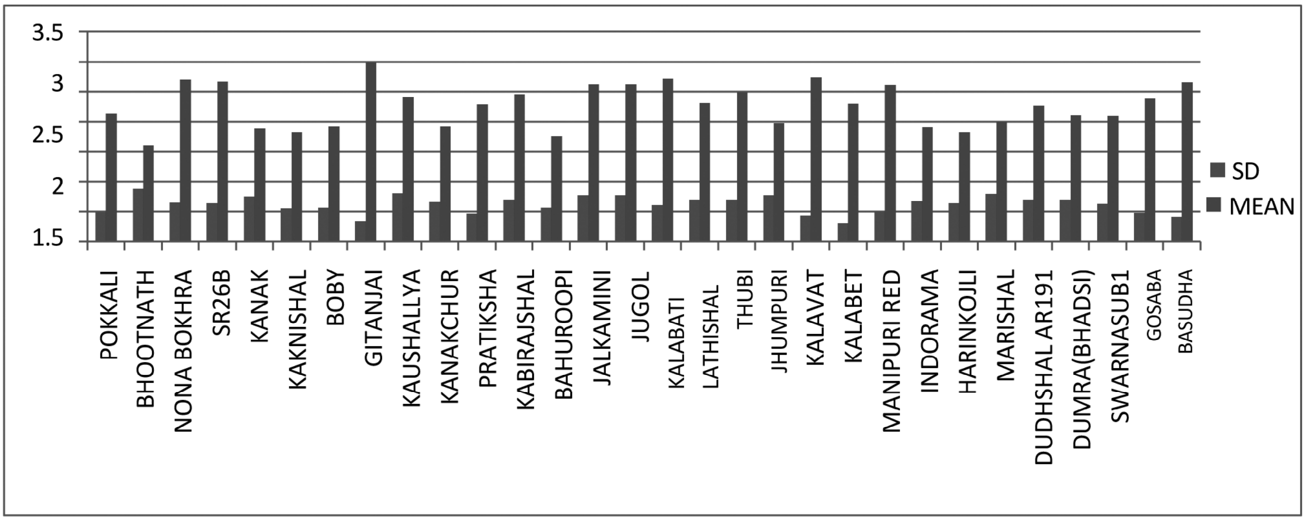
TABLE 2. Amount of protein content in 32 rice genotypes in (%)

VARIETY	CONTROL	6EC	12EC	SD	MEAN
Pokkali(15)	2.63	2.12	1.65	0.49	2.14
Bhootnath(26)	2.58	1.38	0.85	0.89	1.60
Nona Bokhra(17)	3.35	2.68	2.06	0.65	2.70
SR26B(11)	3.27	2.73	1.99	0.64	2.66
Kanak(10)	2.61	1.97	1.10	0.76	1.89
Kaknishal(28)	2.27	2.00	1.20	0.55	1.82
Boby(45)	2.42	2.05	1.31	0.57	1.93
Gitanjali (56)	3.35	2.91	2.69	0.34	2.98
Kaushallya(68)	3.05	2.66	1.50	0.81	2.40
Kanakchur(69)	2.53	2.02	1.23	0.65	1.92
Pratiksha(34)	2.69	2.40	1.78	0.47	2.29
Kabirajshal(P7)	3.17	2.45	1.76	0.70	2.46
Bahuruoi (P1)	2.39	1.54	1.32	0.57	1.75
Jalkamini(P3)	3.30	2.79	1.78	0.77	2.62
Jugol(P8)	3.30	2.79	1.78	0.77	2.62
Kalabati(P11)	3.25	2.85	2.05	0.61	2.71
Lathishal(P12)	2.84	2.58	1.52	0.70	2.31
Thubi(P16)	3.25	2.39	1.85	0.70	2.50
Jhumpuri(P4)	2.58	2.26	1.10	0.78	1.98
Kalavat(P19)	3.19	2.34	2.69	0.43	2.74
Kalabet(P10)	2.61	2.31	2.00	0.30	2.31
Manipuri Red (P23)	3.06	2.71	2.07	0.50	2.61
Indorama (104)	2.58	1.93	1.24	0.67	1.92
Harinkoji(119)	2.34	2.00	1.10	0.64	1.81
Marishal(128)	2.66	2.24	1.11	0.80	2.00
DudhshalAR191(133)	2.82	2.50	1.48	0.70	2.27
Dumra(144)	2.74	2.22	1.36	0.70	2.11
Swarna Sub 1 (146)	2.66	2.22	1.42	0.63	2.10
Gosaba(25)	2.87	2.36	1.93	0.47	2.39
Basudha(121)	3.09	2.61	2.26	0.42	2.65

Fig no : Graphical representation of standard deviation of protein from their mean value



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Adaptive Integrated Pest Management Strategies Under Changing Climatic Conditions

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Abstract

Adaptive integrated pest management (IPM) strategies are increasingly critical for safeguarding agricultural productivity amid global climate change. The dynamic nature of climate variability accelerates shifts in pest populations, alters pest life cycles, and disrupts established ecological balances, presenting new challenges for sustainable crop production. This scientific review explores the evolving landscape of IPM by critically assessing the integration of ecological, technological, and socioeconomic innovations that enable resilient responses to pest outbreaks under changing environmental conditions. By synthesizing recent advances in predictive pest modeling, biological control approaches, precision agriculture, and climate-smart farming, the review highlights how multidisciplinary adaptation strengthens the effectiveness and flexibility of IPM systems. It addresses the complex interactions between climate parameters and pest management practices, emphasizing the need for proactive surveillance, real-time risk assessment, and stakeholder-driven knowledge dissemination. This review article argues for a holistic framework that incorporates genetic diversity, habitat management, and community engagement while using new tools such as remote sensing and data analytics for smarter decision-making. Ultimately, adaptive IPM strategies foster agricultural resilience, support biodiversity, and minimize both economic losses and environmental impacts, paving the way for more sustainable food systems in the face of ongoing climate uncertainty.

Keywords : Integrated pest management, Climate change, Agricultural resilience, Adaptive strategies, Biological control, Precision agriculture, Sustainable food systems

Introduction

Climate change, characterized by rising global temperatures, altered precipitation patterns, and increased frequency of extreme weather events, profoundly affects agricultural productivity worldwide (IPCC, 2021). According to the United Nations, climate change describes the long-term changes we see in global temperatures and weather patterns. While natural factors like shifts in the Sun's activity can influence the climate, human actions remain the main driver. Activities that release large amounts of carbon dioxide, methane, and other gases into the atmosphere are largely responsible for the changes we are experiencing. With its impact on many facets of the ecological, environmental, sociopolitical, and socioeconomic disciplines, climate change is an intergovernmental complicated challenge on a worldwide scale (Leal Filho *et al.* 2021).

These environmental shifts influence pest populations by modifying their distribution, reproductive cycles, and interactions with host plants (Bebber *et al.*, 2013). For example, warmer temperatures accelerate pest development and increase the number of generations per season, thereby intensifying pest pressure on crops (Deutsch *et al.*, 2018). Concurrently, changes in rainfall and humidity affect pest survival and crop susceptibility, often leading to increased outbreaks and crop losses (Pautasso *et al.*, 2013). These developments threaten food security and sustainable agriculture, calling for innovative management approaches.

Integrated Pest Management (IPM) represents a sustainable strategy that combines biological, cultural, mechanical, and chemical controls to manage pest populations effectively while minimizing environmental impact. IPM emphasizes pest monitoring, economic thresholds, and ecological balance focusing on long-term pest suppression rather than short-term chemical responses (Pretty and Bharucha, 2015; Skendžiæ *et al.*, 2021). With climate change increasing pest unpredictability, the adaptive capacity of IPM becomes critically important, allowing timely and site-specific interventions that sustain crop yields and protect biodiversity.

Traditional IPM practices, often based on historical pest trends and fixed schedules, are inadequate under rapidly shifting climatic conditions, which cause novel pest behaviors and distribution shifts. Adaptive IPM involves the integration of real-time monitoring, climate-informed predictive modeling, and flexible decision-making, enabling management strategies that evolve with environmental changes. This flexibility enhances sustainability, resilience, and pest control efficacy, thus maintaining crop productivity amidst climate uncertainty (Zhou *et al.*, 2024). Several significant themes can be outlined for prospective inquiries into the consequences of climatic changes on farming insect pests. These cover the incorporation of unified pest control strategies, the tracking of climate variables and pest trends, and the deployment of predictive analytics tools (Skendžiæ *et al.*, 2021).

This review aims to synthesize recent advances in adaptive IPM strategies within the context of climate change. The goal is to inform policy and practice, ultimately enhancing the resilience of global agricultural systems in the face of ongoing climatic transformations.

2. Review Methodology

A comprehensive review methodology was employed, combining keyword-based searches and transparent reporting following established scientific standards. Relevant literature was sourced from major scientific databases including Web of Science, Scopus, PubMed and Google Scholar. The primary keywords and search terms used were "IPM", "adaptive IPM," "climate change," "sustainable agriculture," "biological control," "pest modeling," "precision agriculture," and "policy frameworks." The search focused on peer-reviewed research articles, reviews, and meta-analyses.

3. Climate Change and Its Effects on Pest Populations

3.1 Overview of Climatic Factors Influencing Pest Lifecycles, Distribution, and Abundance

Climate change modifies key environmental parameters such as temperature, humidity, and precipitation, profoundly impacting pest lifecycles, geographic ranges, and population size. Altered precipitation affects pest survival by influencing habitat suitability and plant host stress, which in turn alters susceptibility to infestation (Pautasso *et al.*, 2013). Additionally, elevated atmospheric CO_2 can change plant chemical composition, potentially influencing herbivore feeding behavior and population dynamics (Stiling and Cornelissen, 2007). Together, these factors reshape pest ecologies with significant implications for agricultural systems.

3.2 Examples of Pest Range Shifts and Phenological Changes Linked to Warming

Empirical evidence indicates that many insect pests and pathogens are shifting their geographic ranges poleward and towards higher elevations in response to global warming (Bebber *et al.*, 2013). Phenological changes such as earlier spring emergence and prolonged activity periods have been observed across multiple pest taxa, disrupting synchrony with natural enemies and exposing crops to longer periods of vulnerability (Forrest, 2016). These shifts complicate traditional pest management timings and call for more dynamic approaches.

3.3 Increasing Frequency of Pest Outbreaks Due to Climate Extremes

The rise in frequency and intensity of climate extremes such as heat waves, droughts, and heavy rainfall events is increasingly linked to episodic pest outbreaks. Not paying attention to how climate change influences crop breeding and sustainable pest control may lead to pest-induced declines in agricultural yield, which will further result in lower global grain availability and higher costs for essential food supplies (Deutsch *et al.*, 2018). Such events can trigger rapid pest population surges that overwhelm existing management systems, undermining crop yields and system stability.

3.4 Challenges Posed by Invasive Species

Invasive pest species are expected to grow more easily in new regions, leading to an increase in insect-borne plant illnesses. The decreased efficacy of biological control agents, or natural enemies, is another unfavorable outcome of climate change that could pose a significant challenge to future pest management initiatives (Skendžiæ *et al.*, 2021). Climate change facilitates the establishment and spread of invasive pest species by creating new habitable zones and disrupting ecological balances. These emerging threats necessitate innovative surveillance and IPM strategies that anticipate and respond to changing pest assemblages under shifting climates.

4. Conceptual Framework of Adaptive IPM

4.1 Adaptive IPM and Its Distinction from Traditional Approaches

Adaptive IPM is an evolution of traditional IPM that explicitly incorporates flexibility, real-time feedback, and learning to cope with the uncertainties and dynamics associated with climate change. Several adaptation measures have been proposed to limit the spread of emerging pests and diseases and to lessen the harm caused by those already present. The strategies most often highlighted include adjusting IPM approaches, closely tracking climate conditions and pest populations, and using predictive modeling tools to guide decisions (Raza *et al.*, 2015). This conceptual shift acknowledges the non-linearity and variability of pest dynamics under changing environmental conditions, allowing for more resilient and context-specific pest control interventions. IPM developed as an approach to pest control that supports more sustainable agricultural growth. It uses a mix of methods to lessen dependence on chemical pesticides while strengthening crop yields and protecting the health of the surrounding ecosystem (Zhou *et al.*, 2024).

4.2 Integration of Ecological, Technological, and Socioeconomic Dimensions

Adaptive IPM integrates multiple disciplinary dimensions to strengthen system resilience:

- **Ecological Dimension:** Incorporation of ecological principles such as promoting natural enemies, habitat diversification, and agroecological practices to maintain ecosystem balance and reduce pest pressures sustainably (Altieri *et al.*, 2015; Gurr *et al.*, 2017).
- **Technological Dimension:** Deployment of precision agriculture tools including remote sensing, drones, IoT sensors, and predictive modeling enhances monitoring accuracy and decision support, enabling precise and timely interventions (Roberts *et al.*, 2021; Getahun *et al.*, 2024)
- **Socioeconomic Dimension:** Engagement with farmers and stakeholders through participatory approaches, supported by enabling policies and economic incentives, ensures adaptation measures fit local capacities and socio-economic realities, promoting widespread adoption and sustainability (Pretty & Bharucha, 2015; Sponsler *et al.*, 2019).

The synergy among these dimensions makes adaptive IPM a comprehensive framework for sustainable pest management under changing climate scenarios.

5. Ecological and Biological Approaches Supporting IPM

5.1 Use of Biological Control Agents and Conservation Biocontrol under Climate Stress

Biological control remains a cornerstone of adaptive IPM, especially under the mounting pressures of climate stress. The use of natural enemies such as predators, parasitoids, and pathogens to control pest populations offers an environmentally sustainable means of pest suppression that can adapt to climate variability.

Biological control is the use of natural enemies to control insects, diseases, and weeds (Baker et al., 2020). Natural enemies like parasitic wasps and predatory arthropods can sometimes drastically lower pest populations (Hajek and Eilenberg, 2018). Common methods for managing endemic pests include releasing commercially available natural enemies on a regular basis, protecting natural enemy populations by offering havens, or refraining from actions that adversely affect them (Dara, 2019). Conservation biocontrol, which focuses on safeguarding and enhancing these indigenous beneficial organisms through habitat management, enhances the resilience of agroecosystems under climate change (Gurr *et al.*, 2017).

Ecosystems, agriculture, and food security are all significantly impacted by the widespread problem of climate change. Ecological balances, particularly the dynamics of insect populations, are being upset by rising global temperatures and changing precipitation patterns. The necessity for advanced pest management techniques that are resilient to the effects of climate change, sustainable, and adaptable has been highlighted by these shifts. By using a wide range of pest management techniques that reduce dependency on chemical pesticides while protecting the environment, integrated pest management (IPM) including biological control presents a viable solution to these problems (Tonnang *et al.*, 2025).

5.2 Promoting Agroecological Practices Such as Crop Diversification and Habitat Management

Agroecological practices such as crop diversification, intercropping, crop rotation, and maintenance of non-crop habitats act synergistically to bolster agroecosystem resilience. By increasing plant and habitat diversity, these practices disrupt pest lifecycles and improve natural enemy abundance, thus reducing pest outbreaks (Tamburini *et al.*, 2020). Habitat management involving cover crops and shelterbelts provides essential resources like nectar, pollen, and refuges for beneficial insects, enhancing biological control services (Gurr *et al.*, 2017). These practices not only mitigate the direct effects of climate variability but also promote ecosystem multifunctionality and soil health, contributing fundamentally to sustainable adaptation.

6. Technological Innovations in IPM under Climate Change

6.1 Role of Predictive Pest Modeling Incorporating Climate Scenarios

Predictive pest modeling integrates climate data, pest biology, and environmental variables to forecast changes in pest distribution, population dynamics, and outbreak risks under varying climate scenarios. These models enable early warning systems by simulating pest behaviour in response to temperature shifts, precipitation changes, and other climatic factors, thus facilitating proactive pest management. The monitoring and decision-making procedures of IPM programs depend heavily on scouting and sampling techniques (Wang *et al.*, 2023). Rearranging IPM can boost global food security, increase farmer incomes, and make agriculture more sustainable (Rossi *et al.*, 2023).

Predictive modeling, which forecasts pest and disease threats using past data and present conditions, can be used into precision agriculture (Ukhurebor *et al.*, 2022). Precision agriculture generally improves the efficiency of managing pests and diseases and supports the resilience and sustainability of agricultural systems (Roberts *et al.*, 2021). Incorporation of climate projections into pest risk assessments supports adaptive IPM by guiding timely interventions and optimizing resource allocation, especially in regions vulnerable to climate variability.

6.2 Precision Agriculture Tools: Remote Sensing, Drones, and IoT for Pest Monitoring

Technological advances in precision agriculture offer transformative capacities for pest monitoring and management. Remote sensing with satellite or aerial imagery provides large-scale, real-time data on crop health, environmental stress, and pest-infected areas. Variable rate technology (VRT), Internet of Things (IoT) devices, GPS-guided equipment, and remote sensing are important parts of precision agriculture technologies

(PAT). Drones and remote sensing provide high-resolution data and images that allow for accurate monitoring of insect activity, soil conditions, and crop health. Accurate planting, fertilization, and harvesting are assured by GPS-guided equipment, which lowers waste and boosts productivity (Getahun *et al.*, 2024).

Examples of remote sensing methods that are increasingly being used to monitor crop health and detect insect outbreaks on a large geographic scale include unmanned aerial vehicles (UAVs), satellite imaging, and aerial photography (Rydhmer *et al.*, 2022; Olson *et al.*, 2021). Using AI through computer vision that is connected to cameras and the internet offers a new method for automated insect detection and monitoring in modern agriculture. As a result, insect surveillance in agricultural systems is much more effective (Preti *et al.*, 2021).

6.3 Data Analytics and Decision Support Systems for Real-Time Adaptive Management

IPM frameworks rely on Action Thresholds (ATs) and Economic Injury Levels (EILs) to ensure that pest management techniques are cost-effective and prevent overuse of pesticides while maintaining crop health and sustainability (Campos *et al.*, 2023). Pest management in forestry and agriculture has emerged as a promising area for the effective use of AI technology, offering creative solutions that are more precise, effective, and ecologically friendly (Streich *et al.*, 2020). The quick development of artificial intelligence in research has led to the emergence of AI-associated theories and techniques, such Smart Pest Monitoring (SPM), as a new scientific field within IPM (Partel *et al.*, 2019) (**Fig. 1**)

7. Policy Dimensions of Adaptive IPM

7.1 Farmer Knowledge Systems to Pest Management

Pest populations are managed below a level where they cannot negatively impact the economy by using IPM. It involves developing out tactics that are economical, workable, and reduce environmental harm (Dara *et al*, 2019). Technology, especially the Internet of Things, might provide a solution that goes beyond traditional farming practices (Angon *et al.*, 2023). IoT can connect sensors and off-the-shelf devices that automate, interpret, and analyze data to direct timely action (de Barbaro, 2019). By automating time-consuming IPM duties like monitoring various data points on a farm and responding to that data, the IPM process becomes more accurate, timely, and less burdensome for the farmer (Dobrojevic & Bacanin, 2022). Farmers' traditional knowledge and experiential understanding of local ecosystems are critical components of adaptive IPM.

7.2 Policy Frameworks Supporting IPM Innovation and Climate Resilience

Policies promoting sustainable agriculture, reducing indiscriminate pesticide use, and incentivizing ecological pest management drive IPM innovation. Integration of climate resilience goals into national agricultural policies ensures that climate-smart agricultural strategies may be implemented (FAO, 2021). Effective policy support involves multi-sectoral coordination, strengthening extension services, funding research, and facilitating public-private partnerships to align IPM with environmental and socioeconomic objectives.

7.3 Incentives for Adoption of Adaptive IPM

Cost-effective pest management options that reduce input costs and enhance crop quality increase farmers' willingness to embrace adaptive strategies. By reducing expenses, farmers can profit financially from the implementation of IPM techniques (Lefebvre *et al.*, 2015). Certain crops, markets, and societies can benefit from consumer understanding of the value of sustainable agriculture, food safety, and environmental protection as well as proof of their willingness to pay for these practices in the form of premiums on agricultural products (Carlisle *et al.*, 2022) (**Fig. 1**).

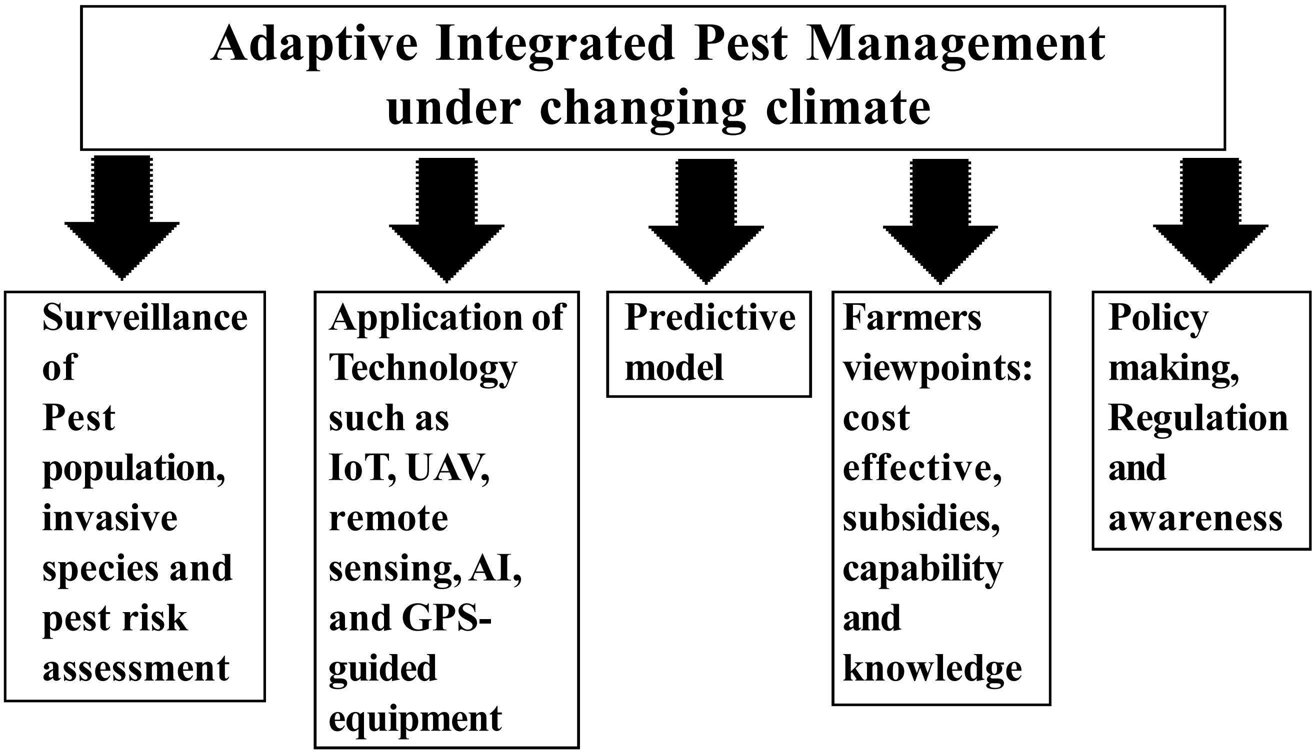

Fig. 1 Schematic diagram showing components of adaptive IPM under changing climate

8. Future Directions and Research Needs

8.1 Bridging Knowledge Gaps in Pest-Climate Interactions

Understanding the complex interactions between climate variables and pest dynamics remains a critical knowledge gap. Future research must prioritize developing high-resolution, ecosystem-based models that integrate pest biology, climate projections, and socio-economic factors to improve predictive accuracy and relevance for local-scale decision-making. Investigating pest phenology, dispersal, and interactions within changing habitats can refine our understanding of pest responses to climate variability and guide adaptive management. Future habitat management initiatives must more effectively manage real-world complications, such as the temporal and geographical impacts in agricultural landscapes and a variety of natural enemies like microorganisms and nematodes (Gurr *et al.*, 2017). To lessen the effects of agricultural pests on crops in a changing environment, altered cropping techniques and adaptive management techniques are required (Skendžiæ *et al.*, 2021). Using effective biological control agents or introducing crop varieties resistant to insect pests through conventional genetic breeding or genetic engineering appears to be essential (Gomez-Zavaglia *et al.*, 2020).

8.2 Enhancing Multidisciplinary Collaborations for IPM Innovation

Addressing the challenges of climate-smart pest management necessitates robust multidisciplinary collaborations that encompass ecological sciences, agronomy, social sciences, economics, and policy-making. Such collaborations foster innovation by integrating empirical research, technological advances, and socio-economic insights, thus creating holistic solutions adaptable to diverse contexts. In order for keeping choice in crop seed sales and to give growers clear instructions on how to conduct scouting using scientifically supported pest thresholds (Pecenka et al., 2021), a “extended peer community” involving farmers, consumers, industry, government, and conservation programs will be essential (Sponsler et al., 2019).

8.3 Growing Adaptive IPM and Global Agriculture

Finding efficient means of educating a vast number of farmers about IPM is still a difficulty. Although a variety of dissemination strategies have been employed, including field days, extension agents, media on paper and online, and using mobile phones, the problem is still present. Support for policies is essential (Pretty and Bharucha, 2015). Planning and developing approaches for mitigation and adaptation, such as improved IPM techniques, pest surveillance and climate monitoring, and the application of modeling tools, is crucial (Skendžiæ *et al*., 2021).

9. Conclusion

Adaptive Integrated Pest Management (IPM) stands at the forefront of sustainable agricultural strategies needed to confront the escalating challenges posed by climate change. The inherent variability and unpredictability of pest populations under shifting climatic conditions demand a flexible, dynamic approach extending beyond traditional static models. Adaptive IPM's strength lies in its ability to integrate continuous monitoring, ecological balance, technological innovation, and social learning to respond effectively and sustainably to evolving pest threats. Its implementation reduces dependency on chemical inputs, conserves biodiversity, and enhances the resilience of agroecosystems, thereby maintaining crop productivity and securing food systems in the face of climate uncertainty.

Ensuring the widespread success of adaptive IPM requires the synthesis of interdisciplinary scientific knowledge, advanced technologies, robust policy frameworks, and inclusive community participation. Cutting-edge tools such as remote sensing, predictive modeling, and data analytics must be integrated with farmer knowledge systems and participatory approaches to contextualize solutions on the ground. At the policy level, empowering frameworks and financial incentives must encourage adoption while safeguarding environmental and human health. The synergistic engagement of stakeholders from scientists and extension agents to policymakers and farmers is essential to scale adaptive IPM effectively, achieving climate resilience and future food security. The urgency of climate-driven agricultural threats necessitates continued investment in interdisciplinary research, innovation, and inclusive governance. Embracing adaptive IPM as a central pillar of climate-smart agriculture will be paramount to securing resilient food production systems that support both people and the planet in the decades to come.

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Assessment of Genetic Variability and Agronomic Performance in Sesame (Sesamum indicum) Under Pre-Kharif Conditions

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Abstract

This study investigates the genetic diversity and agronomic traits of 57 sesame (*Sesamum indicum*) genotypes, with a focus on high yield and early maturity traits under pre-kharif/summer conditions in Randomized Block Design (RBD). Despite sesame's global economic, culinary, and cultural significance, it has received limited research attention compared to other oilseed crops. The study employed ANOVA and coefficient of variation analysis to evaluate the diversity of sesame genotypes for various quantitative traits, including seed yield, capsule count, and plant height. Results revealed substantial diversity, with certain genotypes outperforming popular varieties like Rama and Savitri. The phenotypic coefficient of variation (PCV) was higher than the genotypic coefficient of variation (GCV), suggesting that environmental factors significantly influence trait expression. High heritability estimates were observed for traits such as days to 50% flowering, days to maturity, seed yield, capsule length, number of capsules per plant, and plant height. Traits like number of capsules per plant, plant height, and seed yield showed high heritability coupled with high genetic advance, indicating their potential for selection. Correlation analysis revealed strong positive relationships between seed yield per plant, plant height, number of branches, and number of capsules per plant, suggesting that simultaneous improvement of these traits could enhance seed yield. Cluster analysis identified three main clusters, highlighting genetic diversity, with maximum Euclidean distance observed between genotypes EC-310448(36) and Rama. Principal Component Analysis (PCA) explained 66.429% of the phenotypic variance, with seed yield per plant, plant height, and number of seeds per capsule having the highest loadings. The study concludes that crossing genetically distant genotypes could lead to desirable segregates and enhance sesame productivity.

Key words : Sesame, Genetic diversity, GCV, PCV, Heritability, Correlation

Introduction

Sesame (*Sesamum indicum L.*) is a significant oilseed crop that belongs to the order Tubiflorae and the family Pedaliaceae. It is commonly used in everyday life for various purposes, including in food and cosmetics. Sesame seeds offer several beneficial components, such as antioxidants, vitamins, healthy fats, dietary fiber, moisture, energy, carbohydrates, and minerals. The seeds are composed of 53% oil, 20% protein, 38% oleic acid, and 46% linoleic acid (Dossa *et al.,* 2018). Although Sesamum species can adapt to various environmental conditions, their seed yield is relatively low compared to other oilseed crops (Htwe *et al.,* 2019). Several factors, such as climate, drought stress, pests, diseases, and the absence of high-yielding varieties, can impact productivity. Developing additional high-yielding varieties with broad adaptability could enhance sesame cultivation and productivity.

In crop improvement programs, yield is a crucial characteristic to consider. It is a complex trait influenced by multiple genes and environmental factors. Factors such as crop variety and yield-contributing traits also play a significant role in influencing yield. Improving these yield components can effectively increase productivity (Sreewongchai *et al.,* 2014).

Genetic diversity assessment is a key step in crop improvement, and understanding heritability is essential for selecting traits that can be passed from parents to offspring. Knowledge of the correlation between yield and related traits helps breeders make better selection decisions. Cluster analysis is a broad category of statistical techniques used to group individuals or populations based on genetic similarity. In this study hierarchical clustering has been used to construct a dendrogram where individuals or populations are successively grouped together based on their genetic similarity. This research aimed to evaluate the diversity, correlation, cluster and principal component analysis in sesame, focusing on seed yield and its contributing traits.

Materials and Methods

Experimental site, plant materials, experimental layout and crop management

The field experiment was carried out with 57 genotypes during the pre-kharif season of 2023 at the Agricultural Experimental Farm of the University of Calcutta, Baruipur, Kolkata-700144 (West Bengal). The experimental farm is situated in a hot and humid climatic zone.

Table 3.1. List of genotypes

Sl No	Name of the genotype	Seed coat colour	Centre of origin	Year of release	Parentage
1	EC-310448(36)	Black	Bulgaria (exotic collection, NBPGR)	-	Exotic collections
2	Savitri	Light brown	West Bengal (PORS)	2008	Selection from germplasm SWB32
3	EC-1649666(52)	Black	USA (exotic collections, NBPGR)	-	Exotic collection
4	Rama	Brown	West Bengal (PORS)	1989	Selection from 'Khosla' local
5	IC-204063	Light brown	Indigenous collection, NBPGR	-	Indigenous collection
6	CUMS-06	Dark brown	West Bengal (CU)	-	-
7	CUHY-57(Pragnya)	Light brown	West Bengal (CU)	Identified	Uma x TKG 352
8	CUMS-17(Suprava)	Light brown	West Bengal (CU)	Notified	Mutant of IC 625735
9	V-12	Brown	West Bengal, local land race	-	Local Land Race
10	CUMS-20	Dark Brown	West Bengal (CU)	-	IC 21706 (0.5% EMS)
11	Tilottama	Blackish brown	West Bengal (PORS)	1984	Selection from local germplasm
12	CU-12	Dark brown	West Bengal (CU)	-	OSC593 x NIC8316
13	IC-14053	Brown	Indigenous collection, NBPGR	-	Indigenous collection
14	Thilathara	Blackish brown	Kerela	2006	-
15	JLT-408	White	Maharasthra	2010	Padma x Yuzhi-8
16	RT-351	White	ARS, SKRAU, Mandore	2010	NIC 8409 x RT 127
17	GT-10	Black	ARS, GAU, Amreli (Gujrat)	2002	Selection from TNAU 17
18	AT-306	White	Amreli, Gujrat	-	-

Sl No	Name of the genotype	Seed coat colour	Centre of origin	Year of release	Parentage
19	OSC-593	Dark brown	Bhubenshwar, Odisha (OUAT)	2012	Local land race
20	TKG-22	White	ZARS, JNKVV, Tikamgarh, MP	1995	HT6 x JLT3
21	Germplasm-80	White	Jabalpur, M.P	-	Local land race
22	AT-238	White	Amreli, Gujrat	-	-
23	DS-35	White	Dharwad, Karnataka	-	-
24	Prachi	Black	Odisha (OUAT)	2004	Mutant of B67
25	Shekhar	White	Uttar Pradesh	-	-
26	MT-75 (Pragati)	White	Uttar Pradesh	2002	-
27	Nirmala	White	OUAT, Odisha	2003	Mutant of B-67
28	TKG-306	White	ZARS, JNKVV, Tikamgarh, MP	2006	-
29	TKG-308	White	ZARS, JNKVV, Tikamgarh, MP	2008	-
30	Atghara	Dark brown	Land race	-	Local land race
31	CUMS-01	Dark brown	West Bengal (CU)	-	Mutant line
32	EC-335004(34)	Dark brown	Bangladesh	-	Exotic collection
33	EC-182832(26)	Dark brown	Bulgaria	-	Exotic collection
34	CUMS-19	Dark brown	West Bengal (CU)	-	Mutant line
35	EC-310448 (39)	Black	Bulgaria	-	Exotic collections
36	EC-303435 (4)	Dark brown	USA (exotic collection, NBPGR)	-	Exotic collections
37	EC-334973 (38)	Light brown	Bangladesh	-	Exotic collections
38	EC-320421	Black	Bulgaria	-	Exotic collections
39	IC-55	Bright black	Indigenous variety	-	Indigenous collection
40	P2-23	Brown (mixed)	-	-	-
41	P2-275	Light brown	-	-	-
42	A-21	White	-	-	-
43	P2-22	Dark brown	-	-	-
44	SA-14	Dark brown	-	-	-
45	P-434	Blackish brown	-	-	-
46	P2-25	Light brown	-	-	-
47	P2-9	Whit (mixed black & brown)	-	-	-
48	A-15	Light brown	-	-	-
49	P2-3	Light brown	-	-	-

Sl No	Name of the genotype	Seed coat colour	Centre of origin	Year of release	Parentage
50	P2-5	Dark brown	-	-	-
51	H-11	Light brown	-	-	-
52	A-28	White	-	-	-
53	A-32	Dark brown (mixed)	-	-	-
54	CUMS-17(M)	Dark brown	West Bengal	-	-
55	RAMA(M)	Dark brown	West Bengal	-	-
56	VRI-1	Dark brown	Tamil Nadu	1995	-
57	CU-8	Dark black	-	-	-

Table 3.9 Experimental details of the present investigation

Location	**Agricultural experimental farm, Baruipur, Kol-144**
Season	Pre-*kharif*, 2023
Design	Randomized Block Design (RBD)
Replication	3
Genotypes	57
Spacing	30 x 15 cm
Date of Sowing	03/03/23

In this experiment, fertilizers (N: 50, P: 25, K: 15, S: 15 kg/ha) were applied using urea, single super phosphate, muriate of potash, and elemental sulphur. Phosphorus, potassium, sulphur, and half of the nitrogen were applied as a basal dose at 7 days after sowing (DAS), with the remaining nitrogen applied as a foliar spray at 21 DAS. Intercultural operations included weeding every 15 days, irrigation at critical growth stages, and pesticide application when needed to control pests.

Data Collection

Three randomly selected plants from each variety were taken and data recorded against the following quantitative traits like Days to 50% flowering (days), Plant height (cm), Days to maturity (days), Number of primary branches per plant, Number of capsules per plant, Capsule length (cm), Seeds per capsule, 1000 Seed weight (gm), Seed yield/plant (gm/plant). All measurements were recorded according to the descriptor for sesame.

Statistical Analysis

The analysis of variance, descriptive statistics, correlation and principal component analysis for 9 traits were calculated using SPSS-20 and Cluster analysis was done using DARwin.

Results and Discussion

The present investigation was carried out to evaluate fifty-seven genotypes of sesame in Randomised Block Design (RBD) with 9 quantitative traits. The morphological data recorded for various characters were analysed by using appropriate statistical tools.

Evaluation of genotypes on the basis of quantitative trait data:

Several sesame genotypes outperformed the check varieties, Rama and Savitri, in terms of key traits. Notable high-yielding genotypes like VRI-1, IC-204063, and TKG-306 produced more than 15g of seed per plant, while genotypes such as GERMPLASM-80, H-11, and A-28 had yields below 10g. For capsule count, VRI-1, IC-204063, and CUMS-19 showed over 90 capsules per plant, while GERMPLASM-80, A-28, and AT-238 had fewer than 40. Exceptional genotypes for 1000 seed weight included A-15, EC-310448(39), and P2-9, which exceeded 3.50g, while others like EC-1649666(52) and Rama had weights under 3g.

In terms of flowering, Atghara, VRI-1, and CUMS-O1 took over 40 days to reach 50% flowering, while IC-55, SA-14, and P-434 took less than 35 days. P-434, TKG-308, and P2-9 had more than 55 seeds per capsule, while CUMS-19, Savitri, and EC-90/EC-310448(36) had fewer. Genotypes like EC-103/EC-1649666(52), VRI-1, CU-8, and TKG-306 produced more than 5 primary branches per plant, while others like GERMPLASM-80, AT-238, MT-75 (Pragati), and A-28 had fewer than 2.

For plant height, TKG-306, VRI-1, Atghara, and CUMS-06 exceeded 130 cm, while P2-275, SA-14, and Rama (M) were under 100 cm. Exceptional genotypes for capsule length (2.6 to 3.10 cm) included P-434, TKG-308, A-28, P2-3, Nirmala, and MT-75 (Pragati), while others like CUMS-19, EC-114/EC-303435(4), and IC-55 had capsule lengths below 2.4 cm.

Several genotypes demonstrated early maturity, such as EC-114/EC-303435(4), VRI-1, EC-96/EC-310448(39), and CUMS-19, maturing earlier than Rama and Savitri. In contrast, genotypes like GERMPLASM-80, TKG-22, and A-28 matured later. Overall, the studied genotypes offer valuable potential for breeding high-yielding, early-maturing sesame varieties for summer conditions.

Analysis of Variance:

The analysis of variance revealed highly significant differences among genotypes at $p < 0.01$ and $p < 0.05$ for all 9 traits (Table 2). The analysis of variance depicted the presence of a sufficient scope for variation among the 57 sesame genotypes. Hence, the evaluated varieties can support variation by crossing among them for future generations. These results agree with the reports of Gogoi and Sarma and Kumar *et al.*

Estimation of Genetic Parameters:

The study presents estimates for various genetic parameters like coefficient of variation (CV), genetic coefficient of variation (GCV), phenotypic coefficient of variation (PCV), heritability (H), and genetic advance (GA) for nine morphological traits of 57 genotypes. It was found that PCV was consistently higher than GCV across all traits, indicating the significant influence of the environment on trait expression. The greatest deviation between GCV and PCV was observed in the number of branches per plant, followed by the number of capsules per plant and seed yield per plant. However, traits like days to maturity and capsule length showed lower deviations, and plant height, number of seeds per capsule, and 1000 seed weight exhibited moderate variations.

The highest PCV was recorded for the number of primary branches per plant (44.03%), followed by the number of capsules per plant (35.97%) and seed yield per plant (34.38%). GCV estimates showed a similar trend. High PCV and GCV values were noted for traits like the number of primary branches per plant, number of capsules per plant, seed yield per plant, and plant height, suggesting that these traits are largely influenced by genetic factors, making them suitable for selection. these characters can be relied upon and simple selection can be practiced for further improvement. The results are in conformity with the finding of Patel *et al.* (2022).

Heritability estimates were high for traits like days to 50% flowering (99.05%), days to maturity (87.04%), seed yield per plant (74.58%), and capsule length (74.02%), indicating that these traits are less affected by environmental factors and could benefit

Source	df	Days to 50% Flowering	Days to Maturity	Plant Height	No. of Primary branches/ plant	No. of Capsules/ plant	Capsule length	No. of seeds/ capsules	1000 seed weight	Seed yield/plant
Variety	56	52.52**	13.98**	659.50**	3.69*	1033.4**	0.142	67.04**	0.29	35.59
Replication	2	147.86**	0.98	1615.78**	4.22*	3217.99**	4.84*	207.88**	1.99**	7.54**
Error	112	0.16	0.66	11.34	0.99	17.40	0.01	18.45	0.08	4.34

** = Correlation is significant at the 0.01 level, * = Correlation is significant at the 0.05 level

from selection. Moderate heritability was observed for traits like the number of primary branches per plant (51.94%), number of seeds per capsule (46.75%), and 1000 seed weight (44.01%).

Genetic advance as a percentage of the mean ranged from 3.60% for days to maturity to 35.22% for seed yield/plant. Traits like capsules per plant (30.40%), and primary branches (28.39%) showed high genetic advance, while days to maturity (3.60%), 1000 seed weight (5.67%) and number of seeds/capsule (5.98%) had low genetic advance. These results align with previous studies by Saxena and Bisen (2017), Tripathy *et al.* (2016), Teklu *et al.* (2014), Gidely *et al.* (2012) and Babu *et al.* (2005).

High heritability combined with high genetic advance was observed for the number of capsules per plant (21.69), plant height (17.12), days to 50% flowering (8.52), and seed yield per plant (4.63%), suggesting that these traits are likely to respond well to direct selection. Traits like the number of capsules per plant, number of primary branches per plant, days to 50% flowering, and plant height showed relatively high genetic advance as a percentage of the mean, while days to maturity and 1000 seed weight had the lowest genetic advance. Similar results were reported by Saxena and Bisen (2017), Tripathy *et al.* (2016), Narayanan and Murugan (2013) and Parameswarappa *et al.* (2009), Abate and Mekbib (2015), Teklu *et al.* (2014) for one or more traits.

The study indicates that traits with high heritability and genetic advance, such as seed yield per plant and plant height, are less influenced by environmental factors and are promising for selection.

Correlation Analysis:

The study found strong positive correlations between seed yield/plant and plant height, number of primary branches/plant, and number of capsules/plant, with the highest correlation observed between seed yield and number of capsules per plant (0.891). Days to 50% flowering and maturity showed positive correlations with plant height, branches, capsules, and seed yield, but negative correlation with capsule length.

TABLE 4.4. *Variability parameters for seed yield and yield related traits of 57 genotypes of sesame used for the study*

	CD	C.V (%)	G.C.V (%)	P.C.V	H (%)	GA of Mean	GA %
Days to 50% flowering	0.66	1.11	11.34	11.34	99.05	8.52	19.35
Day to maturity	1.31	0.92	2.40	2.57	87.04	3.77	3.60
Plant height	17.21	9.39	11.91	15.17	61.61	17.12	12.63
Number of primary branches/ plants	1.61	30.52	31.73	44.03	51.94	1.11	28.39
Number of seeds/ capsules	6.94	7.92	7.43	10.86	46.75	3.87	5.98
Number of capsules/plants	21.32	22.11	28.37	35.97	62.21	21.69	30.40
Capsule length	0.19	5.00	8.46	9.83	74.02	0.31	10.78
1000 seed weight	0.47	8.43	7.48	11.27	44.01	0.23	5.67
Seed yield/plant	3.36	18.7	28.97	34.38	70.58	4.63	35.22

Plant height also positively correlated with seed yield, branches, and capsules. The number of primary branches/plant was positively correlated with capsules but negatively with capsule length, seeds/capsule, and 1000 seed weight. A positive correlation between desirable characters is of quite importance to the plant breeder because it helps in simultaneous improvement of both the characters. Thus, selection of any of these characters would lead to the improvement of seed yield/ plant. The correlation studies by and large support observation by Kumar *et al.* (2022), Patel et al. (2010) and Iqbal *et al*. (2016), Who observed the importance of plant height, number of branches/plant and amount of capsules/plant on seed yield/plant.

Cluster analysis:

Cluster analysis of 57 sesame genotypes based on 9 quantitative traits revealed three main clusters. Cluster I, consisting of 51 genotypes, was subdivided into three subclusters: IA (37 genotypes), IB (12 genotypes), and IC (2 genotypes). Cluster II, with 6 genotypes, was divided into IIA (5 genotypes) and IIB (1 genotype). Cluster III contained a single genotype, RAMA(M). The analysis demonstrated genetic diversity within the sesame population, supporting findings from previous studies by Abate *et al.* (2015), Parameswarappa *et al*. (2010), and Ahadu (2012). The largest Euclidean distances were observed between

TABLE Correlation matrix for yield and related traits of 57 genotypes of sesame used for the study

	Day to 50% flowering	Day to maturity	Plant height	Number of branches/ plants	Number of capsules/plants	Capsule length	Number of seeds/ capsules	1000 seed weight	Seed yield/ plant
Days to 50% flowering	1								
Days to maturity	0.698**	1							
Plant hight	0.529**	0.434**	1						
Number of branches/ plants	0.582**	0.600**	0.512**	1					
Number of capsules/ plants	0.453**	0.447**	0.559**	0.711**	1				
Capsule length	-0.301*	-0.350**	-0.38	-0.446**	-0.206	1			
Number of seeds/ capsules	-0.216	-0.258	0.050	-0.382**	-0.096	0.799**	1		
1000 seed weight	-0.131	-0.137	-0.079	-0.341**	-0.267*	0.167	0.211	1	
Seed yield/ plants	0.322*	0.328*	0.543**	0.483**	0.891**	0.046	0.223	0.099	1

**** = Correlation is significant at the 0.01 level, * = Correlation is significant at the 0.05 level,**

Cluster	Sub-cluster	Number of entries	Genotypes
I	A	37	CUHY-57(Pragnya), A-15, RT-351, Prachi, Rama, JLT-408, CUMS-01, DS-35, P2-3, OSC-593, Shekhar, P2-275, P2-9, P-434, GT-10,A-21, EC-112/EC-320421, A-32,P2-25, P2-5, MT-75(Pragati), CUMS-19, CUMS-20, CUMS-06, TKG-308, V-12, Thilathara, EC-113/EC-334973(38), Atghara, EC-84/EC-335004(34), CU-12, EC-96/EC-310448(39), EC 114/EC-303435(4), OSC-593, IC-55, SA-14.
	B	12	AT-238, A-28, TKG-22, H-11, GERMPLASM-80, TKG-306, CUMS-17(M), P2-22, Savitri, Tilottama, EC-90/EC-310448(36), CUMS-17(Suprava).
	C	2	AT-306, P2-23.
II	A	5	IC-64/IC-14053, VRI-1, EC-103/EC-1649666(52), EC-98/EC-182832(26), IC 59/IC-204063.
	B	1	Nirmala.
III	-	1	RAMA(M)

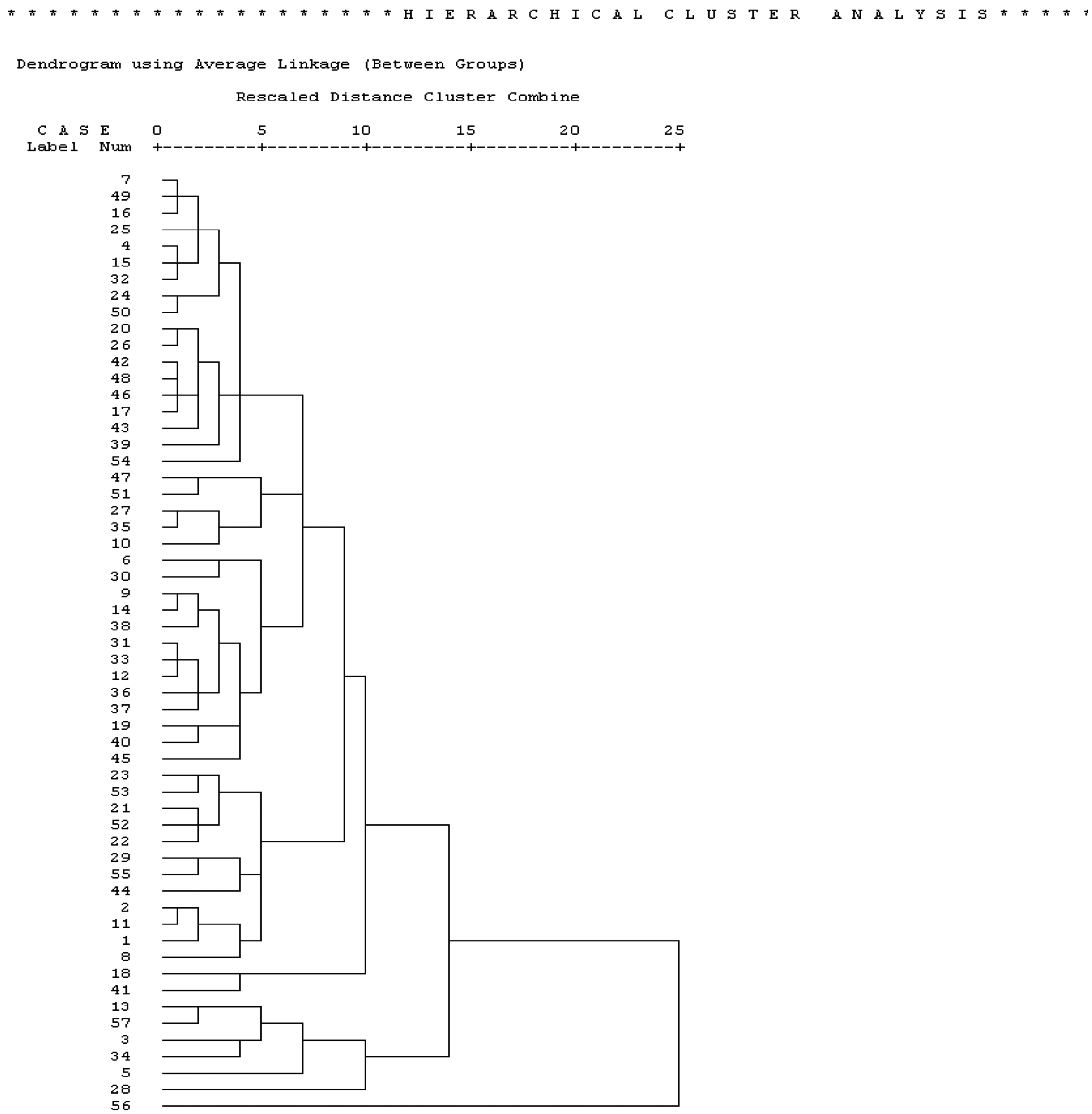
EC-310448(36) and RAMA(M) followed by EC-310448(36) and EC-1649666(52), EC-1649666(52) and Nirmala, EC-310448(36) and EC-182832(26) and EC-310448(36) and Rama. Crossing genotypes with high dissimilarity is expected to yield desirable segregates, making the study valuable for selecting parental materials for breeding.

Principal Component Analysis (PCA) was performed on nine significant quantitative traits of 57 sesame genotypes to identify agronomic traits related to high grain yield. The analysis revealed two principal components (PCs) with eigenvalues e” 1, explaining 66.429% of the total phenotypic variance. PC-1 accounted for 43.931%, and PC-2 for 22.498% of the variation. This finding aligns with previous studies by Choi *et al.* (2017) and Singh *et al.* (2018), highlighting the importance of these components in explaining morphological variations among sesame genotypes.

The Scree plot of the PCA **(Figure-13)** shows that the first two eigenvalues correspond to the whole percentage of the variance in the dataset.

The analysis without rotation of axes failed to provide useful information on the correlation between variables and principal components. However, after applying Varimax rotation, all variables were successfully loaded onto different principal components (PCs). The rotated component matrix revealed that the first principal component (PC-1), explaining 43.931% of the variation, was mainly associated with traits like number of capsules/plant (0.895), seed yield/plant (0.843), plant height (0.781), and number of branches/plant (0.764). The second principal component (PC-2), accounting for 22.498% of the variation, was dominated by traits such as number of seeds/capsule (0.914) and capsule length (0.874). These findings are consistent with previous studies by Shim *et al.* (2016), Singh *et al.* (2018), and Baraki *et al.* (2020).

The principal component (PC) scores, which had both positive and negative values, can be used to develop selection indices. The plot of PC-1 and PC-2 (Fig-14) showed that traits positively contributing to PC-1 included number of capsules/plant, seed yield/plant, plant height, number of branches/plant, days to 50% flowering, days to maturity, and number of seeds/capsule. Traits positively contributing to PC-2 were seed yield/plant, plant height, number of seeds/capsule, and capsule length.



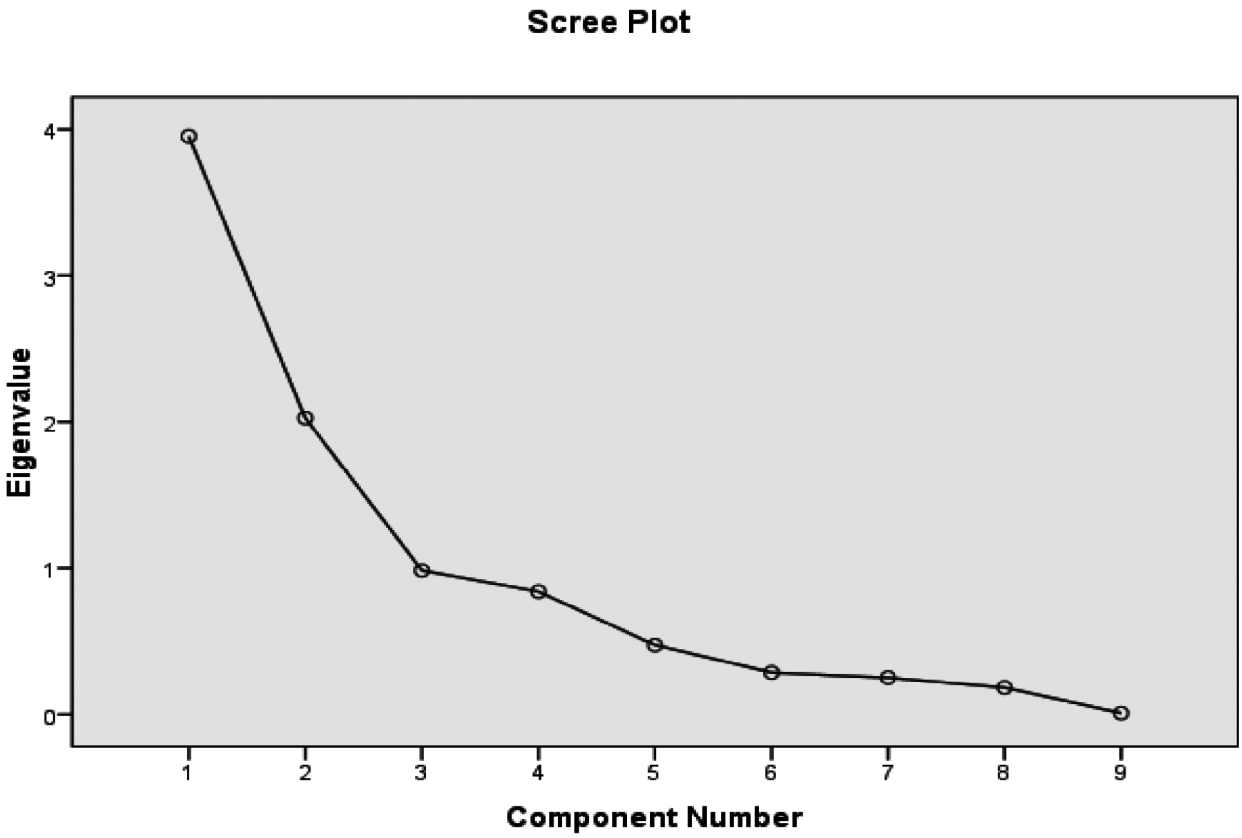
The key traits contributing to variability were seed yield/plant, plant height, and number of seeds/capsule. By reducing the number of variables into three principal components, the study suggests that indirect selection for seed yield based on these component traits could lead to improved genetic recombinants, enhancing yield and related characteristics in sesame.

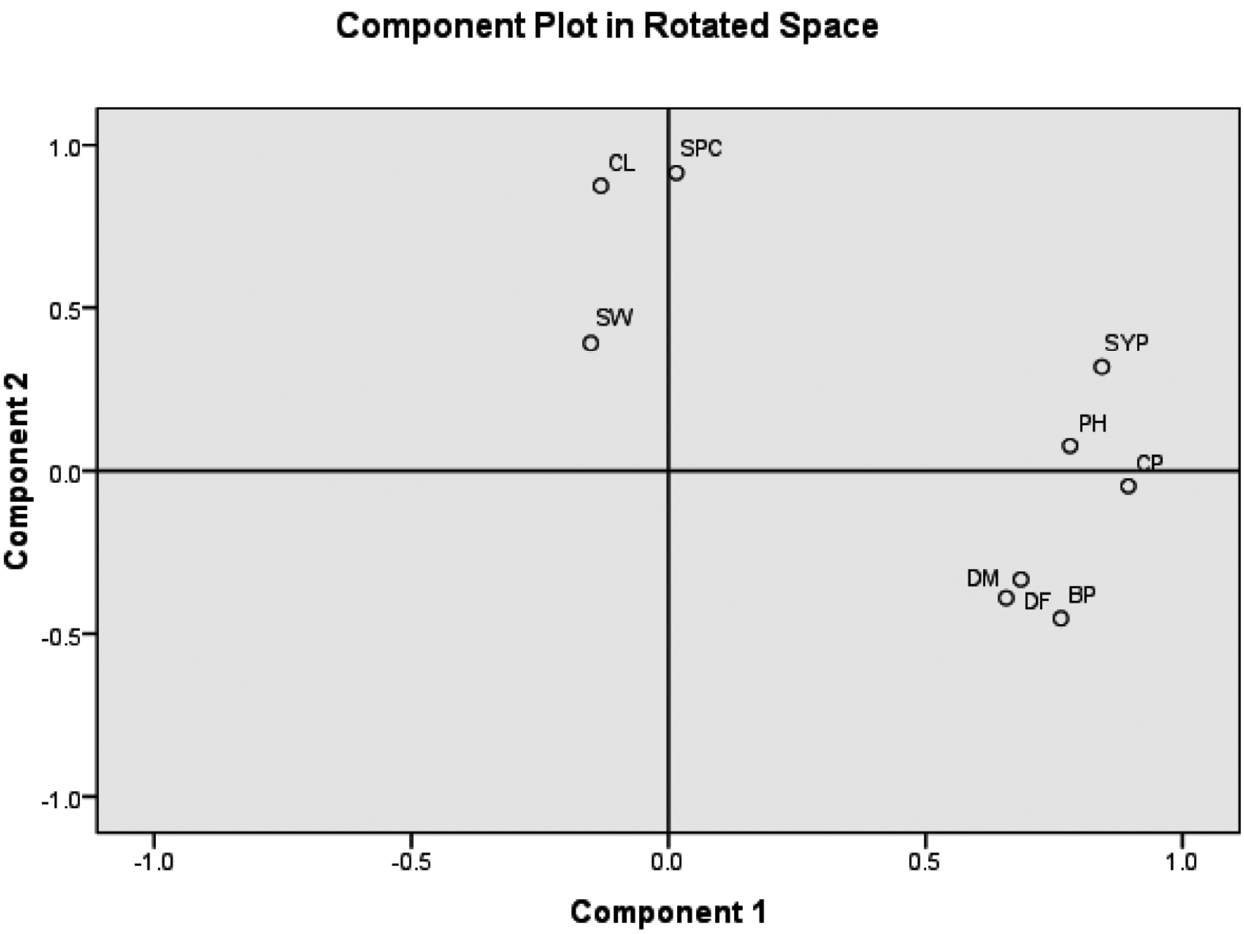
Conclusions

This study on 57 sesame genotypes highlights significant genetic diversity in traits such as seed yield, capsule count, and plant height. The analysis revealed high heritability for several traits, suggesting potential for selection to improve sesame yield. Correlation analysis indicated key relationships between seed yield

TABLE. 4.6. Principal component analysis for quantitative traits of 57genotypes of sesame used for the study

Traits	COMPONENT	
	PC-1	PC-2
Capsule/plant	0.895	-0.047
Seed yield/plant	0.843	0.318
Plant hight	0.781	0.076
Number of branches/lant	0.764	-0.453
Days to 50%flowering	0.686	-0.333
Days to maturity	0.657	-0.390
Number of seeds/capsules	0.015	0.914
Capsule length	-0.131	0.874
1000 seed weight	-0.151	0.392
Eigen value	3.954	2.025
Percentage of variance	43.931	22.498
Cumulative percentage	43.931	66.429





and other traits like plant height and number of capsules, supporting simultaneous improvement. PCA and cluster analysis grouped traits into two main components, explaining 66.429% of the phenotypic variance, and identified critical traits like seed yield and plant height. The findings suggest that crossing genetically diverse genotypes could lead to desirable segregates and improved yield.

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Sewagefed Pond Eco-System in East Kolkata Wetland-a Natural Purification System of Wastewater

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Abstract

Sewage water carries high concentration of heavy metals, soluble/insoluble salts, and inorganic constituents along with hazardous microbial populations. East Kolkata Wetland covers a series of ponds, well connected with each other andutilized for fish culture. Water, sediments and water hyacinth samples were taken from first pond(sewage entry pond) and last pond (pond from outlet used for agriculture). Water hyacinth played a major role by absorbing heavy metals(varied from 10 to 200 times) in different parts like root, shoot and leaves.Physico-chemical characteristics also drastically varied in terms ofpH(7.2 to 7.7), transparency (nil to 15), TDS (675 to 130ppm), TSS(211 to 65ppm), BOD (128.4 to 17.9 ppm), DO (nil to 4.5ppm), alkalinity (273.7 to 130ppm),and free ammonia (40 to 0.5ppm). Decrease in heavy metals in pond water might be attributed to the precipitation of these metals in the sediments, tissue absorption of water hyacinth and root mediated precipitation in the form of insoluble inorganic compounds. Phytoremediation with microbes, planktons and plant played the key role in the natural purification (environmental protection) system of wastewater.

Keywords : pond ecosystem, sewage water, heavy metals, and water hyacinth

Introduction

East Kolkata Wetland (EKW) is well-known for natural purificationof city sewage water. It islocated in between 22°25'N to 22°35'N and 88°20'E to 88°35'E representing a model for multiple use of wetland complexes through resource recovery mechanism, developed by local people with the passage of time (Fig.1). This wetland complex saves the Kolkatacity from the huge costs of constructing and maintaining waste water treatment plants.Nutrient-rich effluent moves through the series of ponds andisprogressively cleaned.Nutrients are redirected to the growth of algae or agricultural products grown along the pond edges and agricultural lands. This wetlands complex naturally recycles nearly 910 million litres per day (MLD) of sewage water generated by Kolkata and its outskirts. EKW purifies 80% of sewage thereby saving Rs. 4680 millionper year of Kolkata ***(Dey D., Banerjee S., 2018)***.

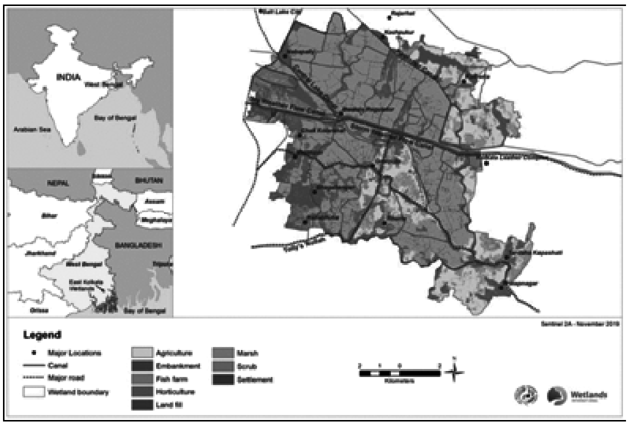

Fig. 1. East Kolkata Wetland Map

EKW spread over an area of 12,500 ha is a mosaic of landforms including predominantly water dominated areas to land centric uses for agriculture, horticulture and settlements. Approximately 234 shallow fish ponds in the EKW receive over 900 MLD pre-settled sewage from the Kolkata Metropolitan region through a network of locally excavated secondary and tertiary canals, which is used to produce annually 20,000 MT of fish, 50,000 MT of vegetables and irrigate 2850 ha of paddy lands. These wetlands also lock over 60% of carbon from wastewater***(Sudin Pal, 2017)***, thus reducing harmful green housegas (GHG) emissions from the region.This wetland performs numerous valuable functions like nutrient recycling, water purification, groundwater recharge, flood management, biogeochemical cycles, carbon sequestration and provision of biological and genetic resources.

High concentration of heavy metals is considered as a leading source of environmental contamination by polluting ground water and poses a serious threat to human health along with the aquatic ecosystem. In view of severe ecological concerns, the present study is undertaken to explore the water quality of the sewage-fed fisheries of the EKW covering the heavy metal in the pond water, sediments and biotic components. The study will evaluate the effectiveness of the existing system and its constraints to maintain the social, ecological, environmental and economic security of Kolkata in the future.

Materials and method

Collection of samples:

The raw sewage canal flows close to the ponds in series where water from the canal is allowed to drain into the pond from time to time by passing through a lock gate preventing the larger particulate matter from entering the ponds. The water is stirred intensely to remove anaerobic conditions in the sediments and to ensure aerobic digestion. There the water undergoes intensive purification throughout the entire volume of the pond(Ray Choudhuri *et. al.* 2008; Ghosh 1998). After purification, this water is used for pisciculture purpose and finally irrigation. The water, sediment and water hyacinth samples were also collected from two different locations of Ponds viz. Captain bheri (pond), Sewage-fed fish pond and the outlet water for agriculture.Water samples were collected fromraw sewage canal, Captain bheri (pond) and outlet water for agricultureat a depth of 50-60 cm below the water surface. Water, sediment and water hyacinth samples are collected from nine(9) locations of each pond.

Sample analysis:

Water samples wereanalyzed following the standard procedures i.e. for pH, EC,TSS (APHA 2540 D), TDS (APHA 2540 C), DO (APHA 4500 C), BOD (APHA 5210 B & 4500C), TC (APHA 9221 B), FC (APHA 9221 E), Pb (APHA 3030 E), Cr (APHA 3030 E), Cd (APHA 3030 E) and Zn (APHA 3030 E)

Results and discussion

Physicochemical analysis (**Table 1**) revealed that the pH of raw sewage and sewage fed fish water in the pond is the near-neutral range whereas the outlet water for agriculture are slightly alkaline in nature. While thetransparency of the raw sewage is nil, it is increased in the sewage-fed fish pond. TDS, TSS, BOD, alkalinity, phosphate, nitrate and free ammonia decreased from 675 to 130 ppm, 211 to 65.0 ppm, 128.4 to 17.9 ppm, 237.7 to 130.0 ppm, 2.94 to 0.8ppm, 3.7 to 2.4ppm and 40.0 to 0.5ppm respectively. In the case of DO,itsvaluein raw sewage is foundto be nil whereas it is increased from nil to 3.9ppm in sewage-fed fish pond and 4.5ppm in the outlet water used for agriculture. It is also observed that in terms of the characteristic parameters of East Kolkata wetland, raw sewage exceeds the effluent standard for inland surface waterexcept few one. Raw sewage after passing through the series of ponds with fish culture and water hyacinth is found to be much purified. The purification process of raw sewage might be due to the absorption of nutrients or eutrophication processes.

The elemental concentration and biological parameters like TC and FC (**Table 2**) showed their presence of Pb, Cd, Cr and Zn at the level of 0.57, 0.32, 5.80 and 0.56 ppm respectively in the raw sewage which is reduced to trace levels in sewage-fed fish pond and outlet water for agriculture. Total coliform and Faecal coliform in the raw sewage were observed as $10^{4.5}$ and $10^{3.5}$ (cfu/100ml) which is reduced to the level of $10^{1.5}$ and $10^{1.0}$ (cfu/100ml) in sewage fed fish

TABLE 1. Characteristics of Raw sewage, sewage-fed fish pond, outlet water for agriculture and effluent standard for inland surface water

Parameter	Raw sewage pond	Sewage-fed fish for agriculture	Outlet water for inland surface water	Effluent standard
pH	7.2	7.5	7.7	5.5-9.0
Transparency	Nil	10	15	10
Total dissolved solid (ppm)	675	455	130.0	2100.0
TSS (ppm)	211	123	65.0	100.0
BOD (ppm)	128.4	25.0	17.9	30.0
DO (ppm)	Nil	3.9	4.5	4.0
Alkalinity (ppm)	273.7	130.0	130.0	83.0
Phosphate (ppm)	2.94	0.8	0.8	0.2
Nitrate (ppm)	3.7	2.4	2.4	0.8
Free ammonia (ppm)	40.0	1.04	0.5	1.2

*** Results are presented the mean value ofnine(9) samples of each parameter**

TABLE 2. Distribution of some elemental concentration and TC &FC status in Raw sewage, sewage fed fish Pond and outlet water for agriculture

Parameter Raw sewage	Captain bheri/Pond Pond	Sewage-fed fish for agriculture	Outlet water for inland surface water	Effluent standard
Cr (ppm)	5.80	Trace	Trace	2.0
Cd (ppm)	0.32	Trace	Trace	2.0
Zn (ppm)	0.56	Trace	Trace	5.0
Pb (ppm)	0.57	Trace	Trace	0.1
TC (cfu/100 ml)	$10^{4.5}$	$10^{1.5}$	$10^{1.5}$	<5000 cfu/100 ml
FC(cfu/100ml)	$10^{3.5}$	10^{1}	10^{1}	<5000 cfu/100 ml

*** Results are presented the mean value of nine (9) samples of each parameter**

pond and outlet water for agriculture. The elemental concentration of raw sewage, except Pb satisfies the effluent standard in contrary to the TC and FC. Deviation in the elemental concentration and TC and FC in raw sewage depends on the source of the waste generation.

The elemental concentration decreases to a reasonable extent while the water passes from the point of generation to the outlet water for agriculture sediment (Table 3). It is revealed that the Cr, Cd, Zn and Pb are decreased from 29.64 to 12.22 ppm, 1.13 to BDL, 49.82 to 11.16ppm and 8.53 to 1.89ppm respectively in the sediments from captain bheri/pond to outlet water sediments. This is most likely brought about by the precipitation of the elements in the soil (Dushenkov *et al.* 1995), uptake by the planktons, as well as uptake by the microbes (Ray Chaudhuri *et al.*

Table 3. Status of elemental concentration in sediments of Captain bheri (Raw sewage), Sewage-fed fish culture and outlet of fresh water for irrigation

Elements	Captain bheri/pond sediments	Sewage-fed fish Pond sediments	Outlet water for agriculture sediments
Cr (ppm)	29.64	17.53	12.22
Cd(ppm)	1.13	0.81	BDL
Zn(ppm)	49.82	36.74	11.16
Pb(ppm)	8.53	6.91	1.89

*** Results are presented the mean value of nine(9) samples of each parameter**

2008). Reports are available on the metal removal (Pb) from water bodies through water hyacinth, tissue absorption and root-mediated precipitation in the form of insoluble inorganic compounds (Dushenkov *et al.* 1995). This could be the possible reason for decrease in metal concentration in water and its increase in the soil of water bodies.

Roots, shoots and leaves of water hyacinth show accumulation for all the above-mentioned elements to a much higher extent compared with its level in the water (Table 4, 5 and 6). The extent of accumulationofCr (17.67, 14.78 and 13.49ppm), Cd (1.21, 0.25 ppm and BDL), Zn (81.52, 47.55 and 28.33ppm)andPb (13.86, 9.72 and 19.11 ppm) within the water hyacinthroots in comparison to the water sample (5.80,0.32, 0.56 and 0.57 ppm) strongly points towards the underlying phytoremediation operating in the water bodies irrespective of the source of water. This holds true in the case of other metals also. The concentration of most of the elements like Cr, Cd, Zn, and Pb is higher in roots as compared to the shoots of water hyacinth. The result corroborates with the findings of Vesk *et al.* (1999). There is relatively less accumulation in leaves in most of the cases (Table 6). There are different processes that are assumed to influence the rate and extent of metal accumulation in plants. These include mobilization and uptake from the external environment (throughrhizo-filtration in case of water plants, Dushenkov *et al.* 1995), compartmentalization and sequestration within the root, efficiency of xylem loading and transport, distribution between metals in skin the aerial parts, sequestration and storage in leaf cells (Clemens *et al.* 2002). The above finding of root accumulationin water hyacinth as compared to other parts couldbe attributedto a less efficient xylem loading as compared to other hyper accumulating plants. This,in turn, is in fluenced by the sesecondary transporters located in endomembranes and the metal lochaper- ones (Clemens *et al.*, 2002). The above results find phyto-remediation, along with elemental precipitation, to be the factors responsible for the decrease in concentration of elements in the pond, thus causing purification.

Conclusion

East Kolkata Wetland has a series of ponds used for fish culture. Water hyacinth in the pond effectively participate in metal accumulation thereby helping in purification of the waste water, which can be recycled in other activities like agriculture and pisciculture. The extent of metal accumulation within water hyacinth varies between a minimum of 10 times to a maximum of 200 times more concentration as compared with the surrounding water. The keystrategy for environmental protection at EKW isbio-remediation with microbes, planktons and plant(phytoremediation).

The total area of the EKWwater body has been reduced from 640 ponds to 234 pondsoverlast 40 years andis still under threat (Chattopadhyay 2001). Land encroachmentcan turn out to be a major threat to this rich ecosystem. In accordance with the present study a multidisciplinary approach like microbial analysis, elemental analysis of vegetable and fishes, economic analysis of the integrated resource recoveryetc is

TABLE 4. Metal content in water hyacinth roots

Elements	Water hyacinth root (mean) Captain bheri(Pond)	Sewage-fed fish Pond	Outlet water for agriculture sediments
Cr	17.67	14.78	13.49
Cd	1.21	0.25	BDL
Zn	81.52	47.55	28.33
Pb	13.86	9.72	19.11

*** Results are presented the mean value ofnine (9) samples of each parameter**

TABLE 5. Metal content in water hyacinth shoots

Elements	Water hyacinth shoots (mean) Captain bheri	Sewage-fed fish Pond	Outlet water for agriculture sediments
Cr	2.11	0.87	BDL
Cd	0.82	0.24	BDL
Zn	21.20	16.2	7.51
Pb	0.057	BDL	BDL

*** Results are presented the mean value ofnine (9) samples of each parameter**

TABLE 6. Metal content in water hyacinth leaves

Elements	Water hyacinth leaves (mean) Captain bheri	Sewage-fed fish Pond	Outlet water for agriculture sediments
Cr	2.19	0.93	0.15
Cd	1.08	0.72	BDL
Zn	26.15	17.34	8.15
Pb	2.97	0.82	0.12

*** Results are presented the mean value ofnine(9) samples of each parameter**

deemed to be highly imperative. The present study is the scientific basis behind the tradition alpracticeofusing water hyacinth for the natural practices for East Kolkata waste water treatmentin these waste waterfed ponds. Considering the immense benefits like, waste detoxification, utilization of detoxified materials (solid as well as soluble) for irrigation and production of food (vegetables, winter paddy and fish), generation of employment, protection of EKW is to be considered with immense importance. Thus, this practice at EKW can act as a role model for tropical countries for waste management.

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Effect of Foliar Nutrients and Growth Regulators on Productivity of Spring Hybrid Sunflower (*Helianthus annuus* L.) in Lower Gangetic Alluvial Soils of West Bengal

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Abstract

An experiment was conducted during the spring season of 2021-22 at the Experimental Farm of the Institute of Agricultural Science, Calcutta University, Baruipur, South 24-Parganas, West Bengal, to find out the effect of foliar nutrients and growth regulators on the growth and yield of spring hybrid sunflower (variety: SIRI-333). The experiment was laid out in a randomized block design with 3 replications and 14 foliar treatments. The foliar treatments were T1-NaCl @0.25% + Turmeric @0.25%; T2-cycocel @0.15%; T3-cycocel @0.2%; T4-cycocel @0.25%; T5-cycocel @0.3%; T6-cycocel @0.2% + KCl @0.5%; T7-cycocel @0.2% + $CaCl_2$ @0.5%; T8-cycocel @0.2% + K_2SO_4 @0.5%; T9- cycocel @0.2% + KH_2PO_4 @0.5%; T10 - cycocel @0.2% + NaH_2PO_4 @0.5%; T11 - $CaCl_2$ @0.5%; T12 -KH_2PO_4 @0.5%; T13 -NaH_2PO_4 @0.5% and T14 -control (water Spray). The foliar sprays were applied at the flowering and seed development stages. It is evident from results that foliar application of cycocel @0.2% combined with KCl @0.5% (T6) significantly improved yield (3.47 t/ha). This study demonstrates the potential of foliar nutrient and growth regulator combinations to enhance sunflower productivity in lower Gangetic alluvial soils of West Bengal.

Key words **:** Foliar Nutrients, Growth Regulators Cycocel, Yield

Introduction

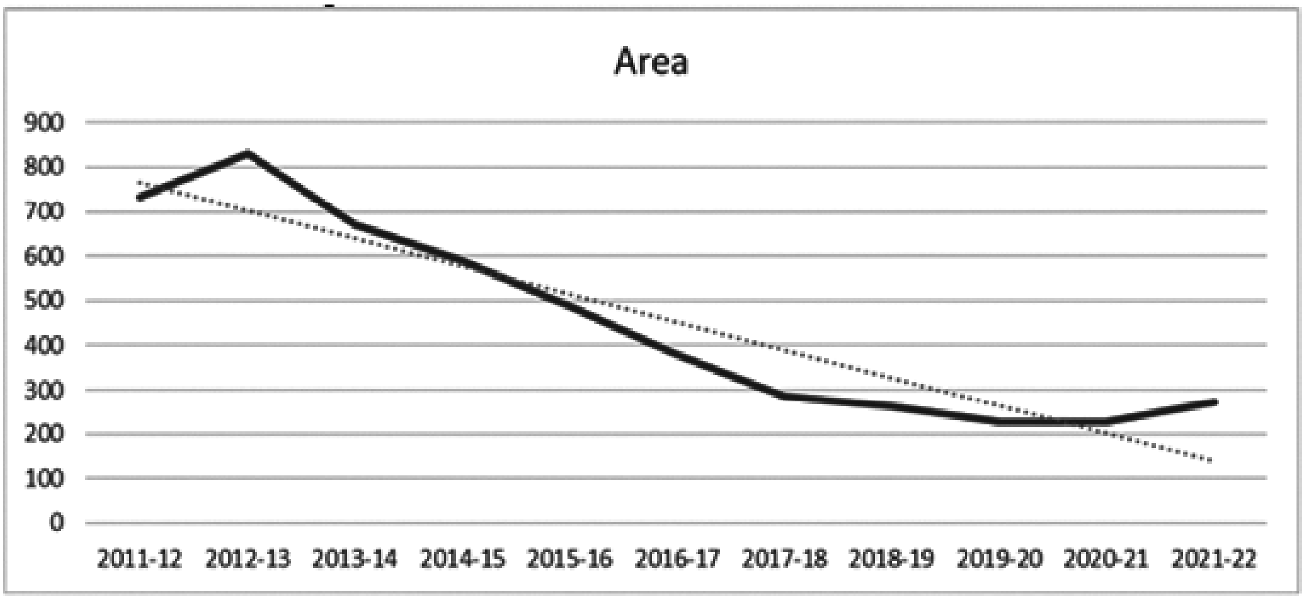
In southern West Bengal, approximately 0.35 million hectares of Gangetic alluvial land remain fallow after the harvest of *aman* rice. Due to late *aman* rice harvesting and delayed water recession from low-lying fields, timely sowing of major winter crops like potato, wheat, rapeseed, and mustard is often unfeasible. Sunflower is a short-duration, photo- and thermo-insensitive crop that's why it offers flexibility in sowing time and can be grown on these fallow lands to meet the shortage of oilseeds in West Bengal during the period between the harvest of *aman* rice and the sowing of the next *kharif* crop. In India, sunflower occupies nearly 0.48 million hectares, producing about 0.32 million tonnes annually, with an average productivity of around 720 kg ha^{-1} during 2019–20 (Ministry of Agriculture, Government of India).

Fig. 1.1 shows that the extent of land devoted to sunflower in India has gradually reduced over the past decade. After a brief rise between 2011–12 and 2012–13, the cropped area steadily shrank from 2012–13 to 2021–22. A comparable pattern is evident in Fig. 1.2, where national production also moves downward during the same period. The sharp fall in both indicators between 2011 and 2020, reflected by growth rates of –15.1% for area and –13.07% for production, has been linked to the widespread occurrence of necrosis disease and the low returns received by farmers. Despite this contraction, yields have shown a modest improvement, which is likely the outcome of farmers gradually adopting better production technologies and management practices (Chandana *et al.*, 2022).

Despite high yielding potential and various advantages of sunflower, the yield per unit area of the crop is low in India which indicates that there is great scope in improving the productivity potential by using suitable measures particularly, the use of plant growth regulators and foliar nutrients.

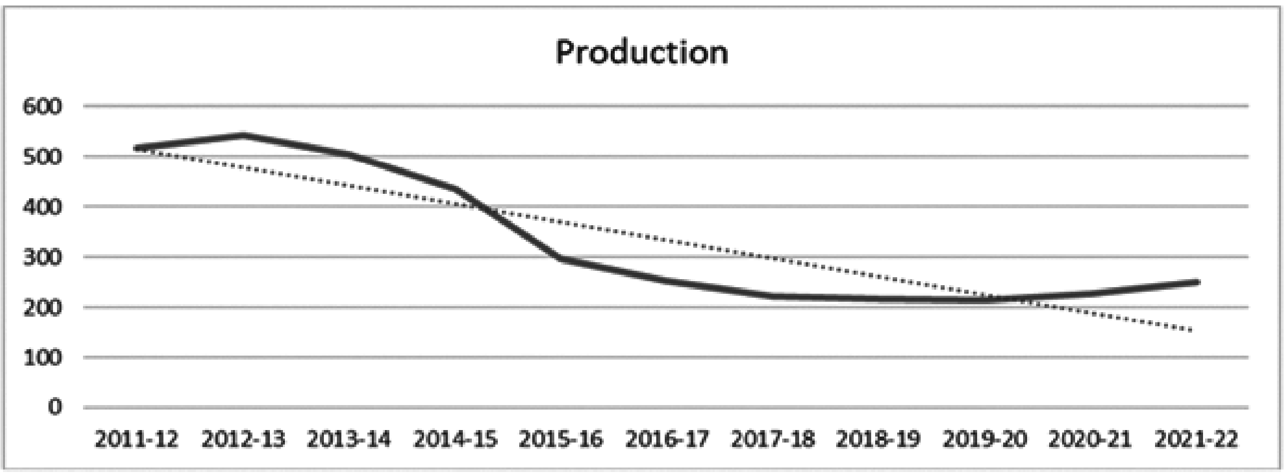
PGRs are considered as "magic chemicals" for their ability to enhance agricultural productivity by modifying plant growth and development patterns, altering physiological and biochemical processes, and improving yields. PGRs, whether promoters, inhibitors, or retardants regulate plant growth by influencing key metabolic processes like nucleic acid metabolism and protein synthesis. Growth retardants reduce internodal distance, thus enhancing the source-sink relationship and promoting translocation of photo-assimilates to seeds (Lui *bet et al.*, 1987). Excessive vegetative growth, poor translocation of photosynthates, and

Fig. 1.1. Area of sunflower crop in India from 2011-12 to 2021-22:



Source: Indiastat.com

Fig. 1.2. Production of sunflower crop in India from 2011-12 to 2021-22:



Source: Indiastat.com

moisture stress during seed development often leads to the production of chaffy seeds (Patil and Dhomne,1997).

Nanja Reddy *et al.*, (2003) emphasized that practices enhancing the mobilization of photosynthates from vegetative parts to the capitulum can improve the harvest index (HI) and seed yield in sunflower. Foliar application of nutrients, combined with PGRs, improves photosynthate translocation and increases seed yield (Prasad and Sastry, 1978). Some growth retardants, such as TIBA and cycocel, mepiquat chloride have been reported to increase photo-assimilate translocation much more in comparison than the growth promoter like kinetin (Pankaj Kumar *et al.*, 2006)

Nutrient demand during late seed development often exceeds a plant's physiological capacity, even in nutrient-rich soils, due to factors like root inactivity and reduced nutrient translocation. Highly soluble nitrogen and potassium fertilizers can leach in soils while phosphate may form an insoluble compound with other minerals hence reducing the availability of nutrients to the plants. Foliar fertilization, especially when applied during the critical growth stages, overcomes these deficiencies by directly providing nutrients to the leaves, thereby improving chlorophyll activity, photosynthesis, and nutrient uptake, subsequently raising yield.

Foliar fertilizers also act as Osmo protectants against environmental stress (Suryavanshi P *et al.*, 2016). The current research aims to further understand the effectiveness of applying these Osmo protectants and PGRs in combating stress, which led to enhanced productivity of sunflower in the Lower Gangetic Plain of West Bengal.

The experiment was conducted at the Agricultural Experimental Farm of Institute of Agricultural Science of University of Calcutta (88^0 28' east longitude, $22^0$22' north latitude and 9.75m altitude), situated in South 24-Parganas district, West Bengal during spring season of 2021-22. The soil of the experimental site was silty clay loam in texture, medium in organic carbon (0.66%), available N (174.3 kg/ha), available phosphorus (29.5 kg/ha) and available potassium (257.2kg/ha) with pH 7.1. The experiment was laid out in randomized block design (RBD) with 14 treatments using hybrid variety SIRI-333. The sowing of sunflower seeds was done by dibbling method to at row to row spacing of 60 cm and plant to plant spacing of 30 cm at a depth of 5-6 cm. A fertilizer dose of 60 kg/ ha N, 80 kg/ha P_2O_5 and 80 kg/ha K_2O was applied. Half of N, entire quantity of P and K were applied at the time of final land preparation and rest of N at the time of first irrigation as top dressing. The foliar treatments were T1-NaCl @0.25% + Turmeric @0.25%; T2-Cycocel @0.15%; T3-Cycocel @0.2%; T4-Cycocel @0.25%; T5-Cycocel @0.3%; T6-Cycocel @0.2% + KCl@0.5%; T7-Cycocel @0.2% + $CaCl_2$ @0.5%; T8-Cycocel @0.2% + K_2SO_4 @0.5%; T9- Cycocel @0.2% + KH_2PO_4 @0.5%; T10 - Cycocel @0.2% + NaH_2PO_4 @0.5%; T11 - $CaCl_2$ @0.5%; T12 -KH_2PO_4 @0.5%; T13 -NaH_2PO_4 @0.5% and T14 -Control (Water Spray). Nutrient solutions were applied @ of 750L/ ha as foliar spray at 50% flowering and seed development stages in the afternoon hours of dry sunny days. Four irrigations were done at 15 days interval. The oil content was determined by using the Soxhlet method based on the extraction of sunflower achenes in a continuous flow extractor and the protein content was measured by Lowry method.

Result and Discussion

***Capitulum Diameter (cm)*:** There were significant differences in capitulum diameter due to foliar treatments (Table 1). The maximum diameter of capitulum with 14.47 cm was recorded in T6 (Cycocel @0.2% + KCl @0.5%), which was at par with T1 (NaCl @0.25% + Turmeric @0.25%) and T8 (Cycocel @0.2% + K, SO„ @0.5%). Minimum diameter for the capitulum were 10.76 cm recorded in T5 (Cycocel @0.3%). All the treatments except T5(cycocel @0.3%) and T12(KH_2PO_4 @ 0.5%) significantly increased the capitulum diameter over the control (water spray). The significant increase in capitulum diameter in T6, T1, and T8 could be due to the growth retardants like Cycocel that have decreased plant height and enhanced

Table 1. Yield attributes and yield of sunflower influenced by treatments

Treatments	No. of seeds/ capitulum	Capitulum diameter (cm)	Test weight (g)	Seed yield (t/ha)	Protein content (%)	Oil content (%)
T1: NaCl @0.25% + Turmeric @0.25%	949	14.13	54.21	2.85	32.86	41.27
T2: Cycocel @0.15%	552	12.73	54.53	2.33	22.01	40.90
T3: Cycocel @0.2%	675	13.98	51.79	2.59	32.83	41.00
T4: Cycocel @0.25%	776	11.28	53.25	1.98	22.61	40.80
T5: Cycocel @0.3%	900	10.76	49.34	1.50	30.95	40.11
T6: Cycocel @0.2% + KCl@0.5%	1156	14.47	54.23	3.47	33.16	41.73
T7: Cycocel @0.2% + $CaCl_2$ @0.5%	712	11.30	50.83	2.01	16.76	40.83
T8: Cycocel @0.2% + K_2SO_4 @0.5%	925	14.09	53.63	2.76	30.18	41.23
T9: Cycocel @0.2% + KH_2PO_4 @0.5%	748	12.13	53.52	2.21	22.96	40.87
T10: Cycocel @0.2% + NaH_2PO_4 @0.5%	850	13.68	51.66	2.45	19.56	40.99
T11: $CaCl_2$ @0.5%	834	13.65	52.12	2.39	19.00	40.97
T12: KH_2PO_4 @0.5%	614	10.91	52.40	1.78	21.03	40.33
T13: NaH_2PO_4 @0.5%	720	12.02	50.99	2.09	21.66	40.87
T14: Control (Water Spray)	603	10.84	50.99	1.70	26.83	40.77
SE(m)±	41.20	0.39	1.22	0.13	-	1.14
CD (P=0.05)	119.77	1.14	3.50	0.37	-	NS

translocation efficiency. According to Pando and Srivastava (1987) and Patil and Dhomne (1997), shortening of the source-sink distance enhances the translocation of photosynthates, hence affecting directly the diameter of the capitulum.

Seeds per capitulum: The pooled data from table 1 revealed that the maximum seed number per capitulum (1156 seeds) was recorded in T6 (Cycocel @ 0.2% + KCl @ 0.5%) which was significantly higher than other treatments. Minimum seed number (552seeds) was obtained in T5 (Cycocel@0.3%). Higher seed number of the cycocel-treated plants, especially T6, aligns with findings by Kene et al. (1991), who reported that foliar application of cycocel enhances seed filling and increases the number of seeds per capitulum. This can be attributed to better distribution of photosynthates towards the developing seeds, as described by Salisbury and Ross (1969), wherein auxins induce the formation of the ovary into fruiting, thus permitting better seed setting.

***Test Weight (g)*:** The test weight of 1000 seeds were significantly affected by the foliar treatments (Table1). The highest test weight (54.23 g) was recorded in T6 (Cycocel @0.2% + KCl@0.5%), and T1 (NaCl @0.25% + Turmeric @0.25%) followed with 54.22 g. The lowest test weight of 49.34 g was recorded in T2(Cycocel@0.15%).

The foliar application of growth regulators such as cycocel at optimal dosages (T6 and T1) has influenced seed development to result in greater test weights. Similar increases in test weight were reported by Uppar and Kulkarni (1999) and Pankaj Kumar (1998) in other crops also with the application of cycocel that supports the role of growth regulators for enhancing seed attributes.

***Yield (tonnes/ha)*: The data table 1 on the yield/ha at harvest clearly indicated that significant difference was observed among the treatments. The maximum yield was 3.47 tonnes/ha and was recorded in T6, that of Cycocel @0.2% + KCl @0.5% which has placed significantly higher over all the other treatments. Minimum yield of 1.5 tonnes/ha was recorded in T5, Cycocel @0.3%. The increased translocation of nutrients towards the seeds and the balanced source-sink relationship facilated by cycocel as reported by Ramprakash and Mangal Prasad (2000) could explain yield improvement in treatments like T6. Similar such results in sunflower were also reported by Sarkar *et al.* (2007) and Mallick and Sarkar, (2009). This growth regulator, Cycocel, helps optimize yields by delaying senescence, thereby increasing the active photosynthesis duration and better partitioning of photosynthates towards the seeds.

***Oil Content (%)*:** It is evident from the Table 1 that the treatments did not have significant difference with respect to oil content, but it was increased in other treatments as compared to control, except T5 (i.e. Cycocel @0.3%). However, T6 (i.e. Cycocel @0.2% + KCl@0.5%) had higher oil content (41.73%) followed by T1 (i.e. NaCl @0.25% + Turmeric @0.25%) (41.27%) and T8 (i.e. Cycocel @0.2% + K_2SO_4 @0.5%) (41.23%) as compared to other treatments. The lowest oil content was observed in T5 (Cycocel @0.3%i.e. 40.11%). The increase in oil content observed in cycocel treatments may be due to its role in enhancing uptake of nutrients and, consequently, better metabolic activity. However, the favorable impacts of cycocel on oil content have been reported in other crops such as cotton, as indicated by Buttar and Aggarwal (2004).

***Percentage of Protein*:** The highest protein content (33.16%) was recorded in T6 (Cycocel @0.2% + KCl @0.5%). This was followed by T1 and T3 with 32.86 and 32.83%, respectively. The lowest protein content of about 16.76% was recorded in T7 Cycocel @0.2% + CaCl, @0.5%). The treatment of cycocel with KCl and K, SO, in T6 and T8 could have enhanced the protein synthesis by better mobilization and uptake of nutrients. This aligns with findings by Kumari *et al.* (2006), who reported an increase in protein content with cycocel application.

Summary and conclusion

In this study an attempt was made to find out the "Effect of foliar nutrients and growth regulators on productivity of spring hybrid (Variety: SIRI-333) sunflower (*Helianthus annuus* L.) in lower Gangetic alluvial soils of West Bengal" and for this one field experiment was conducted at Experimental farm of Calcutta university, South 24 Pargana during the year 2016-17. The experiment was conducted in Randomized Block Design with 14 foliar treatments, comprising different combinations of Cycocel growth regulator and nutrients like KCl, $CaCl_2$, and KH_2PO_4, and so on. Under this research, the targeted key performance parameters included capitulum diameter, seed yield, protein content, and oil content.

Results showed that the highest yield was achieved by the foliar treatment with Cycocel @0.2% + KCl @0.5 (T6), and it was 3.47 t/ha. In addition, an increase in the diameter of capitulum was observed up to 14.47 cm and in test weight up to 54.23 g along with an increase in protein content up to 33.16%. The lowest results were indicated by control or water spray treatment and by the treatment with Cycocel @0.3% (T5). However, the oil content did not differentiate the treatments except T6, which showed the maximum value recorded, which was 41.73%.

The study reveals that foliar application of cycocel along with the essential nutrient improves significantly the productivity of hybrid sunflower in fallow Gangetic alluvial lands, and this practice is an effective method that should be followed for improving oilseed production in West Bengal.

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Effects of Various Planting Techniques and Biofertilizer Application on Growth and Nutrient Uptake of *Valeriana Jatamansi* : Valuable Medicinal Herb of Himalaya Range

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Abstract

Valeriana jatamansi Jones (Family: Caprifoliaceae), a high value medicinal plant, was distributed in many countries of Asia. It is a reputed perennial medicinal herb distributed in high altitude of himalaya range in India. This is used in cytotoxicity, neuronal problems, insomnia, leishmania and acetyocholinesterase inhibitor, antioxidant, antiviral and alpha glucosidase inhibition activity. An experiment was carried out at Regional Research Station, under the aegis of Uttar Banga Krishi Viswavidyalaya, Kalimpong (1265 m asl) to evaluate the effect of different planting methods and biofertilizer application on physiological growth and economical yield of *Valeriana jatamansi*, under the mid hill condition of West Bengal. Present investigation was conducted in split plot design with three replication, having four methods of planting in main plot and different sources of biofetilizer (eight treatments including control in sub plot. Observation revealed that, ridge method of sowing produced notable higher fresh biomass production throughout the growth phase and significantly better to other method of planting at all stages of data recording except at 18 month stage. With biofertilizers, more aerial biomass was registered with the azotobacter + VAM + PSB(@ 2 + 2 + 2 g/plant), and was at par with the VAM + PSB(@ 2 + 2 g/plant) at 6, 9 and 12 month stage. Underground biomass gave significant response with various main plot actions, ridge planting gave more biomass production at all stage of data recording. More fresh underground biomass registered with the incorporation of azotobacter + VAM + PSB(@ 2 + 2 + 2 g/plant) at all stage of data recording except 18 and 21 month. Increase fresh rhizome yield was noticed with the ridge method of planting and notably better to all the treatment under main plot except at 15 month old crop, and was at par with the furrow sowing at 24 month stage. Under subplot treatments, application of azotobacter + VAM + PSB(@ 2 + 2 + 2 g/plant) gave more rhizome yield except at 21 and 24 month stage, and was at par with the azotobacter + PSB(@ 2 + 2 g/plant) at 9 month and with azotobacter + VAM(@ 2 + 2 g/plant) during 9 and 12 month old crop. More root yield reading was found with the ridge sowing. Amongst various biofertilizers incorporation, under subplot more root yield was registered with the azotobacter + VAM + PSB(@ 2 + 2 + 2 g/plant) except at 24 month, and was at par with the VAM + PSB(@ 2 + 2 g/plant) from 15 to 24 month stage of crop. Nutrient uptake pattern and concentration was found to be superior with ridge sowing methods compare to rest of the main plot treatments. Amongst sub plot treatments, combine incorporation of biofertilizer gave more yield and more nutrient absorbed from the soil. Above experiment depict that, utmost plant physiological growth was observed with ridge sowing along with application of azotobacter + VAM + PSB (@ 2 + 2 + 2 g/plant) under mid hill situation.

Key words : Biofertilizer, medicinal plant, planting methods, yield.

Introduction

Valeriana jatamansi is one of the most important medicinal herb of the western to eastern Himalayan grown at an altitude of 1200 - 2000 m. It is distributed from Afghanistan to southwest China, Burma and few part of Indian Himalayan range (Mukherjee *et al*., 2013). Like many other non-timber forest products (NTFPs), this vulnerable plant (*Valeriana jatamansi* Jones; Syn. *Valeriana wallichi*) is taken as forest gift and hence there is neither any control system in its harvest nor its domestication. Locally tribal people used this as medicinal purpose especially for headache and eye trouble. Medicinal plant play critical role in tribal life particularly in remote part (Kant and Yadav, 2014). In Ayurvedic medicine, it is used as aromatic, stimulant, carminative, and antispasmodic. It is also used for the treatment of epilepsy and hysteria (Chakraborty *et al.*, 2015). Powdered drug, mixed with sugar is used in urinary troubles. A decoction of the drug is reported to be given in Nepal to mothers after parturition, probably as a sedative. Although the economic value of the herb was reportedly unknown to the local people until recent past, the herb has now been widely known for its market potential (Chakraborty *et al.*, 2015a). Thus, the exploitation of this plant is increasing leading to its rapid decline from its natural habitat in Himalayan range. *Valariana jatamansi* inhabit diverse habitats of Darjeeling – Sikkim Himalaya, so it was thought worthwhile to undertake detailed plant behaviour that enables the species to survive in these varied habitats (Mukherjee, 2022). The species witnessed a tremendous decline in its population size due to its poor germination and agronomic management (Mukherjee, 2009). It tells the tale of biotic interferences, which have brought it to the brink of extinction. If left as such and exploited at the same rate, in near future, the species will disappear forever. Rhizome is an item of commerce and is being sold to different trading centres in the region. Farmer's or inhabitant of different forest location, particularly in Eastern Himalaya, as per our survey revealed that, they could not know how to improve its production, agronomic package and conservation of this valuable treasure of this earth. Our observation revealed that, method of planting and proper organic nutrient management plays an important role in productivity of *Valeriana jatamansi*. Drastic reduction in yield of seed and rhizome has been recorded with the broadcasting or bad method of planting in terraced land situation. Wrong planting methods exposed plant to both the extreme of temperature. i.e. low temperature during early growth period, which restrict the vegetative phase and high temperature during post vegetation phase of life cycle, which reduce the duration of rhizome and root development and consequently the crop yield as a whole (Mukherjee, 2014). Effective biofertilizer strains play vital role for crop canopy development, and act as important soil mulch for various beneficial nutrients (Kumar *et al*., 2017). Till date very little work has been conducted on this plant particularly good agronomic practices particularly in the field of planting methods and biofertilizer application. Keeping this aspect in mind, present work was undertaken to examine influence of various planting methods and biofertilizer application on growth and economic yield of *Valeriana jatamansi*.

Materials and Methods

An experiment was carried out during the year of 2010 - 2014 with the objective of to find out influence of various planting methods and biofertilizer application on growth and economic yield of *Valeriana jatamanasi*- a valuable medicinal plant of Darjeeling hill. Present study was conducted under the aegis of Uttar Banga Krishi Viswavidyalay, at Regional Research Station, Kalimpong. Planting materials for this experiment was mainly raised from seed which, collected from lava forest. Seed was chosen for experiment, keeping in mind that, this would help easy to propagate and farmer friendly also. The soil of the experimental site was sandy loam having pH 5.2 with moderate available nitrogen, phosphorus and potassium (Jackson, 1973). Analyzed soil sample data presented in Table 1.

Table 1. Physico-chemical status of soil sample

pH	*ECE (inch/cm)*	*Available (kg/ha)* N	P_2O_5	K_2O	*Total N (%)*	*Organic C (%)*	*Organic matter (%)*	*C/N ratio*
5.2	0.3	298	22.1	314	15.22	3.54	2.474	14.13

Mature seed were collected during end of February, 2010 and March 2012, and kept in paper bags of convenient size after proper labelling. The fruit were shed dried in the open air and gently hand shaken while inside the paper bag. Sowing of seed in a nursery bed was done under careful observation with finally sieved and well sterilized (in autoclave) clay soil in the 10^{th} and 16^{st} April, respectively in 2010 and 2012. Meteorological data indicate that during these months day – night temperature of the experimental sites varied between 6 and 24^{0} C, probably meeting the optimum temperature requirement of this species and resulting in higher germination with less time for completion. Germinated seed were transplanted in main field during the month of 30th June, 2010 and 2nd July, 2012 in main field. Field experiment was conducted in split plot design with three replication, having four methods of planting in main plot (viz. plain bed sowing, sloppy land sowing, furrow sowing and ridge sowing). Various source of biofetilizer were accommodate in sub plot which includes mainly eight treatments (viz. control, azotobactor (@ 4 g/plant), PSB(@ 4 g/plant), VAM(@ 4 g/plant), azotobactor + PSB(@ 2 + 2 g/plant), azotobactor + VAM(@ 2 + 2 g/plant), VAM + PSB(@ 2 + 2 g/plant), and azotobactor + VAM + PSB(@ 2 + 2 + 2 g/plant)). The irrigation was given and other recommended packages of practice were adopted during the crop growth period in both the years. Data on growth pattern was taken at 3 month intervals as per normal procedure. The significant differences between the treatments were compared with the critical difference (CD) at 5 % level of probability (Gomez and Gomez, 1984). Plant and soil sample were analyzed for uptake of nitrogen, phosphorus and potash as per standard laboratory procedures (Jackson, 1973). Available phosphorous was determined by Olsen's method as outlined by Jackson (1973), using spectrophotometer (660 nm wave length). Available potassium was extracted with neutral normal ammonium acetate and the content of K in the solution was estimated by flame photometer.

Results and Discussions

Growth and economical yield characters, significantly influenced by various planting methods and biofertilizer application. This play critical role in growth of *Valerina jatamansi*- a valuable herb of Darjeeling Himalaya (Mukherjee *et al*., 2015). Fresh aerial biomass was significantly influenced by various main and subplot treatments (Table 2). Observation revealed that, ridge method of sowing produced notable more fresh biomass production throughout the growth phase and significantly better to other method of planting at all stage of data recording except at 18 month stage. Further, this treatment was at par with the sloppy land cultivation at 21 and 24 month stage of data recording. Ridge sowing improve better fresh aerial biomass production mainly due to less water stagnation, which reduced the change of disease incidence and improve fresh biomass production. At 18 month stage more aerial biomass was registered with the sloppy land sowing and was at par with the plain bed sowing methodology, and statistically superior to rest of the main plot treatments combination. With various biofertilizers application under sub plot, at all stages, more aerial biomass was registered with the azotobactor + VAM + PSB(@ 2 + 2 + 2 g/plant) and was at par with the VAM + PSB(@ 2 + 2 g/plant) at 6, 9 and 12 month stage and with, azotobactor + PSB(@ 2 + 2 g/plant) at 12 month of data recording, and statistically better to all other sub plots treatments during four year of data recording. Underground biomass gave significant response with various main plot treatments, ridge planting gave more biomass production at all stage of data recording (Table 3). This treatment was at par with the furrow sowing methods, during 6,9 and 15 month stage of observation and at 15 month, this treatment showed parity with the plain bed sowing methods. With various subplot treatments, more fresh underground biomass registered with the incorporation of azotobactor + VAM + PSB(@ 2 + 2 + 2 g/plant) at all stage of data recording except 18 and 21 month. This treatment was at par with the Azotobactor + VAM(@ 2 + 2 g/plant) at 12 month and with VAM + PSB(@ 2 + 2 g/plant) at 15 and 24 month stage of data recoding. Critical observation of table 2 revealed that at 21 month more fresh underground biomass was registered with the azotobactor + PSB(@ 2 + 2 g/plant) and was at par only with the azotobactor + VAM + PSB(@ 2 + 2 + 2 g/plant). Rhizome yield gave good response with various planting methods and biofertilizer application in subplot treatments (Table 4). Higher fresh rhizome yield was noticed with the ridge method of planting and significantly better to all the treatment under main plot except at 15 month stage, and was at par with the furrow sowing at 24 month stage of data recording. Table 4 revealed that at 15 month more fresh rhizome weigh produced with the furrow method of sowing and was at par with the plain bed method of planting. Rhizome is very important part of *Valeriana jatamansi*, and its production significantly affected by various method of planting. This result is very fruitful for jatamansi growers in Darjeeling himalays [11]. Under subplot treatments, application of azotobactor + VAM

Table 2. Effect of different planting method and nutrient management practices on fresh aerial biomass of *Valeriana jatamansi* at periodical interval (pooled data of four years)

Treatments	Fresh aerial biomass / plant (g)						
	6 month	9 month	12 month	15 month	18 month	21 month	24 month
Main plot (Methods of planting)							
Plain bed sowing	4.01	7.89	22.11	51.26	56.36	63.59	70.22
Sloppy land sowing	3.01	5.69	12.56	28.98	58.56	70.36	77.26
Furrow sowing	2.11	7.36	18.78	33.36	44.98	55.98	65.26
Ridge sowing	4.89	10.66	29.36	59.60	50.36	73.69	81.98
SEm±	0.29	0.52	1.27	1.81	1.32	1.94	2.09
CD (p=0.05)	0.78	1.37	4.36	5.11	4.39	5.35	7.41
Sub plot (Biofertilizers application)							
Control	2.11	3.69	15.69	23.65	29.89	39.25	45.36
Azotobacter (@ 4 g/plant)	3.26	6.35	24.36	33.36	39.66	46.32	58.69
PSB(@ 4 g/plant)	3.87	6.79	20.36	23.64	31.26	39.68	52.39
VAM(@ 4 g/plant)	3.59	5.06	16.11	18.69	28.11	41.23	53.69
Azotobacter + PSB(@ 2 + 2 g/plant)	4.36	7.89	26.98	38.66	47.36	54.36	66.36
Azotobacter + VAM(@ 2 + 2 g/plant)	4.10	9.36	23.65	36.11	41.23	50.35	60.23
VAM + PSB(@ 2 + 2 g/ plant)	5.36	12.08	27.36	41.32	46.98	55.36	65.11
Azotobacter + VAM + PSB (@ 2 + 2 + 2 g/plant)	6.39	12.69	30.33	51.23	59.69	63.98	79.36
SEm±	0.39	0.69	1.36	1.55	2.45	1.69	3.21
CD (p=0.05)	1.22	2.36	4.52	5.36	6.33	5.64	8.69
CV	9.69	14.63	12.33	17.89	12.11	11.36	16.36

TABLE 3. Effect of different planting method and nutrient management practices on underground biomass of *Valeriana jatamansi* at periodical interval (pooled data of four years)

Treatments	Fresh underground biomass / plant (g)						
	6 month	9 month	12 month	15 month	18 month	21 month	24 month
Main plot (Methods of planting)							
Plain bed sowing	1.58	2.56	5.10	28.69	49.31	58.69	69.11
Sloppy land sowing	1.33	1.89	4.56	15.66	22.33	36.87	48.23
Furrow sowing	1.78	3.11	6.33	27.02	48.65	60.36	68.98
Ridge sowing	2.39	3.78	8.98	31.21	59.39	68.69	81.33
SEm±	0.23	0.29	0.36	1.36	1.54	1.98	2.03
CD (p=0.05)	0.66	0.83	1.12	4.56	4.87	5.87	6.98
Sub plot (Biofertilizers application)							
Control	0.71	2.66	4.66	13.36	23.36	32.65	42.11
Azotobactor (@ 4 g/plant)	1.36	4.65	8.89	23.75	39.69	56.23	63.36
PSB(@ 4 g/plant)	1.45	3.41	8.44	21.98	43.25	53.68	68.25
VAM(@ 4 g/plant)	1.98	3.96	8.98	23.31	37.22	48.36	65.21
Azotobactor + PSB (@ 2 + 2 g/plant)	3.58	6.36	15.23	30.11	58.69	69.33	79.36
Azotobactor + VAM(@ 2 + 2 g/plant)	3.35	6.65	18.66	29.65	40.88	48.36	67.21
VAM + PSB(@ 2 + 2 g/plant)	1.96	5.33	13.36	34.81	45.33	57.36	78.48
Azotobactor + VAM + PSB(@ 2 + 2 + 2 g/plant)	6.56	7.89	19.65	39.69	52.15	64.85	84.25
SEm±	0.28	0.30	0.86	1.36	1.01	1.39	1.44
CD (p=0.05)	0.69	0.87	2.36	5.69	3.88	4.69	6.12
CV	15.02	18.39	17.36	12.36	14.58	13.36	14.36

Table 4. Effect of different planting method and nutrient management practices on rhizome yield of *Valeriana jatamansi* at periodical interval (pooled data of four years)

Treatments	Fresh rhizome yuield / plant (g)						
	6 month	9 month	12 month	15 month	18 month	21 month	24 month
Main plot (Methods of planting)							
Plain bed sowing	0.43	0.51	0.99	12.11	20.87	16.71	20.85
Sloppy land sowing	0.32	0.23	2.11	6.68	8.77	14.51	18.97
Furrow sowing	0.63	1.31	2.86	13.33	22.29	22.77	27.76
Ridge sowing	0.84	2.11	4.65	10.61	29.23	26.08	27.32
SEm±	0.07	0.19	0.12	0.63	0.98	0.56	0.23
CD (*p*=0.05)	0.19	0.60	0.38	1.98	2.36	1.76	0.87
Sub plot (Biofertilizers application)							
Control	0.17	1.68	3.41	8.8	16.38	23.67	22.86
Azotobacter (@ 4 g/plant)	0.24	3.29	4.53	12.39	24.45	33.58	34.11
PSB(@ 4 g/plant)	0.13	1.35	3.46	12.09	25.59	24.32	37.56
VAM(@ 4 g/plant)	0.96	2.18	5.00	13.42	21.53	22.67	33.53
Azotobacter + PSB(@ 2 + 2 g/plant)	2.19	4.25	10.01	13.72	42.23	48.97	50.38
Azotobacter + VAM(@ 2 + 2 g/plant)	2.06	4.59	14.37	15.06	23.19	22.67	36.85
VAM + PSB(@ 2 + 2 g/plant)	0.62	2.17	8.00	14.55	23.97	22.97	27.59
Azotobacter + VAM + PSB (@ 2 + 2 + 2 g/plant)	3.8	3.31	13.39	20.81	30.89	28.49	37.62
SEm±	0.26	0.34	0.71	1.14	0.87	1.56	1.55
CD (*p*=0.05)	0.66	0.98	1.78	3.36	2.60	5.36	4.36
CV							

+ PSB(@ 2 + 2 + 2 g/plant) gave more rhizome yield at all stage of data recording except at 21 and 24 month stage, and was at par with the azotobacter + PSB(@ 2 + 2 g/plant) at 9 month stage and with Azotobacter + VAM(@ 2 + 2 g/plant) during 9 and 12 month stage of observation. However at later growth phase, azotobacter + PSB (@ 2 + 2 g/plant) gave more rhizome yield particularly at 21 and 24 month stag of observation, and significantly superior to rest of the treatments under subplot. Root is one of the most important aspects of plant growth and it has great economic importance particularly in case of Indian Valeriana (Mukherjee, 2016). This parameter gave significant response at most of the phase of plant growth, with innumerable number of treatment and its combination under main as well as in subplot (Table 5). Perusal of table 5 revealed that, under main plot treatment at 6 and 9 month stage all the methods of planting failed to produced any notable response, however more fresh root yield reading was found with the ridge sowing method. Further, interpretation of result revealed that remaining stage of data recording, ridge sowing produced significant response and showed parity with the plain bed method sowing during 12, 18, 21 and 24 month stage of observation. Amongst various biofertilizers incorporation, under subplot more fresh root yield was registered with the azotobacter + VAM + PSB(@ 2 + 2 + 2 g/plant) except at 24 month, and was at par with the VAM + PSB(@ 2 + 2 g/plant) from 15 to 24 month stage of observation. Critical observation of table revealed that during the harvesting stage more root yield result from VAM + PSB(@ 2 + 2 g/plant) (50.89 g/plant) and showed parity with the azotobacter + VAM + PSB(@ 2 + 2 + 2 g/plant) (46.63 g/plant). This treatment gave 164.3 and 142.5 % more root yield compare to rest of the treatment combination at this stage. Literature revealed that VAM play crucial role in fungal growth through mycelia, it help to improve root strength as well as plant architecture, and this is the main cause of good growth of plant with this biofertilizer combination. Significantly very poor response of root yield was observed from the control plot and it was followed by azotobacter (@ 4 g/plant) and PSB(@ 4 g/plant).

Nutrient content of plant and soil was significantly affected by various treatment combination under main and subplot treatments (Table 6). Nitrogen content (%) in aerial biomass failed to produce any significant response with various sowing methodology. However, amongst various treatments under main plot, nutrient content (%) in aerial biomass, particularly phosphorus and potassium was observed with the ridge sowing and showed parity with sloppy land sowing only for potassium. Various subplot treatment revealed that azotobacter + VAM + PSB (@ 2 + 2 + 2 g/plant) had more N, P, K content and was at par with the azotobacter + PSB (@ 2 + 2 g/plant), and with VAM + PSB(@ 2 + 2 g/plant) for phosphorus and potassium, VAM(@ 4 g/plant) for potassium only. Nutrient content in underground biomass (%), showed significant response only with nitrogen and potassium content, and its failed to reply any response with phosphorus. Significantly more N and K underground biomass resigsterd with the ridge sowing methods. With biofertilizer application under various subplot treatments, more N, P, K content was observed with the azotobacter + VAM + PSB (@ 2 + 2 + 2 g/plant) and was at par with the azotobacter + PSB (@ 2 + 2 g/plant), and with VAM + PSB(@ 2 + 2 g/plant) only for N and P only. Nutrient uptake by aerial biomass (g/plant) failed to gave significantly reply with phosphorus and potassium. Observation revealed that, more nitrogen uptake was observed with ridge method of sowing, and significantly better to rest of the treatments under main plots. Subplot treatment revealed that, application of azotobacter + VAM + PSB (@ 2 + 2 + 2 g/plant) absorbed more primary nutrient and was at par with the azotobacter + PSB (@ 2 + 2 g/plant), VAM + PSB(@ 2 + 2 g/plant) for potassium, and all the treatment for phosphorous uptake except control plot. Nutrient uptake by underground biomass (g/plant) produced good reply with the various main plot treatments, and it was more observed with the ridge method of sowing. This treatment was at par with the sloppy method cultivation for N and P, and plain bed method only with for P. Further, table 6 revealed that with various subplot treatments incorporation of azotobacter + VAM + PSB (@ 2 + 2 + 2 g/plant), more absorbed primary nutrient and was at par with the VAM

Table 5. Effect of different planting method and nutrient management practices on root yield of *Valeriana jatamansi* at periodical interval (pooled data of four years)

Treatments	Fresh root yield / plant (g)						
	6 month	9 month	12 month	15 month	18 month	21 month	24 month
Main plot (Methods of planting)							
Plain bed sowing	1.15	2.06	4.11	16.58	28.44	41.98	48.26
Sloppy land sowing	1.01	1.69	2.46	8.98	18.56	22.36	29.26
Furrow sowing	1.15	1.80	3.47	13.69	26.36	33.59	41.22
Ridge sowing	1.55	1.68	4.33	20.60	30.16	46.61	54.01
SEm±	0.19	0.20	0.19	1.06	0.77	2.08	1.65
CD (p=0.05)	NS	NS	0.54	3.58	2.89	6.35	5.89
Sub plot (Biofertilizers application)							
Control	0.54	0.98	1.25	4.56	6.98	8.98	19.25
Azotobacter (@ 4 g/plant)	1.12	1.36	4.36	11.36	15.24	22.65	29.25
PSB(@ 4 g/plant)	1.32	2.06	4.98	9.89	17.66	29.68	30.69
VAM(@ 4 g/plant)	1.02	1.78	3.98	9.89	15.69	25.69	31.68
Azotobacter + PSB(@ 2 + 2 g/plant)	1.39	2.11	5.22	16.39	16.39	20.36	28.98
Azotobacter + VAM(@ 2 + 2 g/plant)	1.29	2.06	4.29	14.59	17.69	25.69	30.36
VAM + PSB(@ 2 + 2 g/plant)	1.34	3.16	5.36	20.26	21.36	34.39	50.89
Azotobacter + VAM + PSB (@ 2 + 2 + 2 g/plant)	2.76	4.58	6.26	18.88	21.26	35.36	46.63
SEm±	0.23	0.26	0.13	0.89	0.36	0.93	1.45
CD (p=0.05)	0.68	0.89	0.39	2.36	1.26	2.69	4.89
CV	9.23	12.31	15.11	15.09	12.16	17.21	15.98

NS : Non significant

TABLE 6. Effect of various treatments on nutrient content and uptake pattern at maximum growth stage (pooled data of four years)

Treatments	Nutrient content in aerial biomass (%)			Nutrient content in underground biomass (%)			Nutrient uptake by aerial biomass (g/plant)			Nutrient uptake by underground biomass (g/plant)		
	N	P	K	N	P	K	N	P	K	N	P	K
Main plot (Planting methods)												
Plain bed sowing	3.44	0.32	1.51	2.53	0.34	1.43	0.72	0.061	0.29	0.164	0.010	0.064
Sloppy land sowing	3.51	0.29	1.67	1.86	0.30	1.29	0.75	0.068	0.31	0.172	0.011	0.072
Furrow sowing	3.17	0.22	1.39	2.19	0.31	1.38	0.63	0.055	0.28	0.144	0.008	0.054
Ridge sowing	3.98	0.36	1.72	3.87	0.39	1.71	0.88	0.071	0.35	0.186	0.013	0.086
SEm±	0.21	0.02	0.03	0.17	0.03	0.08	0.03	0.005	0.02	0.005	0.001	0.013
CD (p=0.05)	NS	0.06	0.09	0.54	NS	0.24	0.09	NS	NS	0.015	0.003	0.027
Sub plot treatments (Biofertilizer application)												
Control	2.11	0.22	1.15	0.61	0.16	1.11	0.28	0.007	0.21	0.094	0.002	0.031
Azotobacter (@ 4 g/plant)	2.78	0.23	1.40	2.43	0.21	1.41	0.72	0.063	0.29	0.161	0.004	0.039
PSB(@ 4 g/plant)	2.98	0.27	1.41	2.58	0.29	1.58	0.70	0.061	0.24	0.153	0.006	0.021
VAM(@ 4 g/plant)	3.11	0.28	1.51	2.49	0.22	1.50	0.74	0.060	0.31	0.158	0.005	0.059
Azotobacter + PSB (@ 2 + 2 g/plant)	3.63	0.36	1.52	3.09	0.36	1.81	0.85	0.068	0.35	0.159	0.008	0.086
Azotobacter + VAM (@ 2 + 2 g/plant)	3.28	0.29	1.56	2.55	0.28	1.55	0.76	0.071	0.31	0.181	0.011	0.064
VAM + PSB(@ 2 + 2 g/plant)	3.41	0.32	1.51	3.03	0.34	1.73	0.83	0.061	0.33	0.165	0.009	0.078
Azotobacter + VAM + PSB (@ 2 + 2 + 2 g/plant)	3.87	0.38	1.65	3.18	0.40	1.87	0.95	0.078	0.40	0.173	0.010	0.098
SEm±	0.11	0.03	0.04	0.12	0.03	0.05	0.05	0.009	0.02	0.012	0.005	0.008
CD (p=0.05)	0.29	0.10	0.14	0.34	0.09	0.13	0.17	0.027	0.07	0.035	NS	0.023
CV	13.25	11.26	11.02	8.12	7.33	8.96	9.68	12.58	7.65	6.39	7.58	12.36

NS : Non significant

+ PSB(@ 2 + 2 g/plant), azotobactor + PSB (@ 2 + 2 g/plant) for N and K. Further data revealed that, all the biofertilizer application produced significant response with nitrogen uptake and play crucial role in plant composition. As we know nitrogen play critical role during protein synthesis and other vital metabolic activity of plant body (Mukherjee, 2018). Study revealed that, amongst various treatments, utmost plant physiological growth was observed with ridge sowing along with application of azotobactor + VAM + PSB (@ 2 + 2 + 2 g/plant)under mid hill situation of Darjeeling himalaya. Optimum transplanting during the June month with ridge sowing with proper biofertilizer application (region based) is best suited, for higher yield of herb and economic production per unit area of land. This ultimately more beneficial to growers in turn higher net return.

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Heritage Rice Heist : who's Accountable for Disappearance of Local Varieties from Farmers' Field ?

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Once hailed as the savior of billions hungry Indians, the semi-dwarf High Yielding Rice varieties (HYV) are now here and there being denounced as a harbinger of destruction. People antagonistic to HYV rice argue that the proliferation of these contemporary rice varieties extensively throughout the nation, poses a detriment to the artistry and essence of traditional rice cultivation. To these critics, modern varieties are perceived as the merciless slayers of heirloom rice diversity, jeopardizing the natural resilience against pests and diseases, and accelerating the degradation of soil and the environment. Questions have even been raised about their potentiality and achievements. So celebrated yield superiority of HYVs over traditional rice is being claimed as just a story and propaganda by the state agricultural scientists and extension staff to promote its cultivation claimed by Ashraf and Lokanadan in International Journal of Current Microbiological Applied Science 2017. Is it not imperative to thoroughly investigate the rationality of the allegations before relentlessly accusing a friend in times of distress?

The birth and diversity of domestic rice

Currently the paddy we cultivate, the rice we eat, had no existence at all in the Nature. Nearly seven thousand years before Jesus' birth in Jerusalem, Asian cultivated rice emerged from the ancestral womb of wild rice, Oryza rufipogon revealed by Molina and his co-researchers in the Proceedings of National Academy of Science 2011. Such a profound evolution from a wild, weedy perennial to a cultivated, annual rice with upright stems and strongly bound rice was guided by natural mutation of four pivotal genes (SH4, QSH1, Prog1 locus and RC) of wild ancestor and the discerning selection pressure of ancient farmers (E, Callaway, 2014). This transition didn't happen overnight. Instead, it's been a slow unfolding across a thousand years, showcasing the enduring partnership between humans and nature. As nature meticulously sculpted the wild form of rice, yielding a myriad of variants genetically tuned for survival and proliferation in diverse environment, ancient farmers embarked on a quest, handpicking boasting superior yield, tantalizing taste and fortitude against pest and diseases. Survival of natural rice variants thus depended solely on the preferences of our farming ancestors. Unless the variants aligned with farmers' choices, they are supposed to fade away over time. It is therefore evident that since the inception of rice cultivation, the fields have been gradually losing the rice varieties disliked by farmers. HYV rice came into existence many millennia later.

Archaeological records indicate that in Indian sub-continent the cultivation of Asian rice originated in Ganges valley of North-East in 6500BC documented by Durai and co-workers in Indian Journal of Plant Genetic Resources 2015 .The genetic modification of rufipogon boosted the adaptability of Asian rice to such an extent that its cultivation spread rapidly across the country much like a blazing wildfire in no time. From the arid, desolate soils to the rich fertile plains, the story of rice cultivation unfolds. It spans the rugged terrains of the Himalayan foothills, descending the icy heights to the warm, briny marshes or the untamed, green low lands below. Such is the vast expanse of its reach. Nature adapted the genetic makeup of rice to thrive and reproduce in such varied agro-environments. This process gave rise to numerous variants or varieties of rice tailored to meet specific condition and preferences of local farmers. According to eminent rice scientist TT Chang (1989), domesticated rice varieties exhibit greatest diversity within the geographic belt stretching from North East India to South East China. With India particularly West Bengal nestled within this belt, it's no surprise that these regions showcase a lush tapestry of rice diversity.

The exact count of rice varieties is a mystery; but their multitude of names and uses hints at the vastness of biodiversity. Renowned rice scientists R. H. Richaria, along with Govindaswamy claimed in their book "Rice in India" that India once cultivated 2,00,000 varieties of rice. In contrast, experts like Paroda and Mallick, as well as organizations like IGMORIS, estimated the number of traditional rice varieties in India to be 50,000. In 1955, scientists led by S. Gobindaswami began the India's first exploration of rice biodiversity, collecting 1,745 indigenous rice varieties through extensive search over a period of five years (1955-59) in 27,000 square kilometres area of the Jaipur region, now known as Koraput district. In a separate effort from 1967 to 1972 M.S.Swaminathan and S.V.S.Shastri collected 6,000 indigenous rice lines in Northeast India, known as Assam Rice Collection. R.H.Richaria also made substantial contributions between 1970 and 1979. He collected 19,226 local rice varieties, known as the Raipur Collection, from 42 districts of Madhya Pradesh. Again in 1971, under the initiative of IARI, Hyderabad, Sharma and his fellow scientists gathered altogether 8,000 local rices from the hilly areas of Meghalaya, Arunachal Pradesh and Assam in the first phase and Manipur, Tripura and Mizo Hills in the second phase. Various States also joined this venture in 1950s. Accordingly the total number of indigenous rice varieties collected at both State and National level and accessed at NBPGR reached 66,000 up to 1982. Out of which 50 percent were same rice varieties with different Accession numbers. In fact, collection of local rice in NBPGR stood at 36,000 up to 1982 **noted** by Hore and Sharma in the Indian Journal of Forestry, 1991. Currently the NBPGR(National Bureau of Plant Genetic Resources) has a rich collection of 1,04,538 rice Accessions. However, not all of these are indigenous. This collection includes wild species, exotic varieties, improved breeds, and unknown mixtures. When FAO analysed the classification of these varieties, the NBPGR had 86, 119 varieties, out of which only 18%(approximately 15, 501) were indigenous. Later an additional 18, 419 varieties were added, bringing the total to1, 04, 538 by 2022. Even assuming all the newly added varieties were indigenous, the total would be 33, 920 indigenous varieties, which is still far less than the 2,00.000 documented by Richaria and Gobindaswami or the 50,000 by Paroda and Mallik. This highlights the difference between estimation and reality.

Let's also look at the post-independence West Bengal's rice biodiversity. Estimates vary, with Pal listing 5000 varieties in News Research, 2016 and Deb identifying 15000 in Gastrnomica, 2021. Notably in the 1970s BRRI scientists reported the existence of 12,479 indigenous rice varieties in Bangladesh. In West Bengal , the Chinsurah Rice Research Station began collecting indigenous rice varieties in mid-1950s, eventually amassing 5000 indigenous varieties. Of these 60 were detailed in 1962 publication " Recommended Varieties of Paddy for West Bengal" by the State's Department of Agriculture. Beyond the Chinsurah Rice Research Station various NGOs in State have also collected indigenous rice varieties over the years. Different collections include 610 varieties reported by Deb in the Bioscience Research Project Commentaries, 2009, 106 varieties (ARSWS,Purulia) and 233 varieties identified by Dey in the Beats of Natural Science, 2014. Many of these may be duplicates of those documented in Chinsurah or collected under different names. Even assuming no overlaps, the diversity of indigenous rice in post-independence West Bengal would not exceed six to six and half thousand, and likely less, as many entries are duplicates. This perspective is supported by number of enlisted indigenous rice varieties documented in W.W. Hunter's " A Statistical Account of Bengal (Part-1)" following his exploration during 1870s in undivided Bengal. Hunter's list depicted in 24 parganas district, covering 10,000 sq miles, 129 varieties of Aus and Aman rice were cultivated. In the Sundarbans district, only 37 varieties were grown in two seasons. It is worth mentioned in this context that many of the indigenous varieties found in the fields of 24 parganas during Hunter's survey in 1870 , such as Disbere, Dismoni, Khirkone, Menki etc were found missing in the subsequent survey by the Department of Agriculture. Instead, new set of indigenous varieties like Tulshijhuri, Gheus, Hamiltion, Kalomota etc were discovered. It can therefore, be reasonably assumed that these newer varieties performed better in similar agro-situations and farmers replaced the inferior varieties with superior new ones. Isn't the farmer's intense desire for improved performance the reason for disappearance of old indigenous rice varieties in this case ?

The Dawn of High Yielding Rice on the Indian Canvas

In 1947, when the British left India, country's food situation was extremely dire, exacerbated by the partition which took away our key wheat and rice growing areas. By 1950, the population had reached 361.1 million but the domestic food production of 50.82 million tones was insufficient to meet the basic needs. The global post-war recovery further limited import options. Despite an agreement with USA to import 10.6 million tones food grains between 1956-1959 and subsequent renewals for even larger quantities, these imports drained India's exchequer and failed to resolve food crisis. Up to mid 1960 the Indian efforts to increase food production concentrating largely on expanding farming areas with improved local varieties did not yield significant results. Faced with a persistent food shortage, India recoursed to increasing the yield of the country's two principal food crops, rice and wheat. At this pivotal moment, news broke of a ground breaking development in the field of IRRI: the long-waited rice variety, IR8, had finally come to fruition. This extraordinary variety had been a vision of the experts from the International Rice Commission as far back as 1949. IR8 in semidwarf stature and 130 days maturity duration promised astonishing yield, producing 10 tons per hectare with 120 kg Nitrogen fertilizer and 5 tons without any nitrogen input. At the helm of IARI, the visionary Dr Swaminathan recognized the immense potential of IR8. His unwavering advocacy, coupled with the endorsement of the then Minister of Agriculture, led the Central Variety Release Committee to make a historic decision to release the variety across the country in 1966.

In 1967, the evolutionary adoption of semi-dwarf HYV rice began in the remote village of Atchanta in the west Godavari district of Andhra Pradesh. It was spearheaded by a 29-year-old progressive farmer, N. Subbarao. When the new IR8 rice variety was cultivated across a vast area of Subbarao's land, it yielded astonishing results. Curious villagers flocked to witness this miracle. They observed in awe, as this short duration, hardy newcomer produced yield three times higher than the traditional varieties they were accustomed to. Dreams of golden future filled their eyes. The entire harvest from Subbarao's field was used as seed for the following year, leading to cultivation of IR8 rice on 1600 hectares within the same village. The wave soon spread throughout Andhra Pradesh, then to Tamil Nadu, Karnataka, and Hyderabad, and eventually across the entire country. Hot on the heels of IR8 came other varieties like Jaya, Padma etc. As these HYV rice varieties spread like wildfire, they began to transform the landscape of rice production in India. In 1950, rice production stood at 20.8 million tons from30.8 million hectares. By 1969-70, this had surged to 40.8 million tons, without significant expansion of rice area. The key to this revolutionary increase was tripling of yield rates. Within three decades of introducing HYV rice, India not only became self-sufficient in rice production but also started amassing buffer stock of 15.7 million tons annually. From being a traditional importer of rice, the country thus transformed into a self-reliant producer, banking on semi-dwarf HYVs.

Some have historically contested these facts, claiming that high yield potentiality of these varieties was exaggerated by the Government officials and the farmers were coerced into cultivating them. Opponents of HYV further argue that these varieties are hybrids, created by crossing indica and japonica strains, with japonica being particularly susceptible to pest and diseases. They allege that these has led to wide spread pest and disease problems across the country, while traditional varieties supposedly remain unaffected. However, none of these assertions are true. These varieties are neither hybrids nor the result of indica-japonica crossbreeding. Like any other traditional varieties, they are all inbred. IR8 is actually a semi-dwarf derivative resulting from Indonesia's high-yielding tall indica variety, Peta, and Taiwan's dwarf indica variety, Dee-geo-woo-gen. The magic behind this semi-dwarf variety and its high yield lies in a gene named sd-1. This gene is located on chromosome number one of Dee-geo-woo-gen variety. Its function is to reduce the synthesis of the gibberellin growth hormone (GA 20 oxidase) in rice cells. As, result the inter nodal regions of rice stem become shorter, making the plant dwarf and sturdier. This structural change means that even with heavy grain heads, the plant does not topple over. This modification significantly alters the plant's physiology. The sd-1 gene not only prevents unnecessary elongation of the plant, thereby reducing the expenditure of produced dry matter, but also efficiently redirects this conserved dry matter towards producing more grains, thereby increasing yield. That's the extent of sd-1 gene's role – it's the key to the dramatic yield increase. In terms of biomass production, there's not much difference between HYV rice and traditional varieties. However, yield difference is enormous, making all the difference in productivity. A 2020 study by Panth also highlighted that farmers gain much higher profits from cultivating HYV rice compared to traditional varieties, primarily because the yield is three times greater. Critics often downplay this yield potential by attributing it to the use of fertilizers and irrigation. However, just as the sun is the ultimate source of energy in the universe, the seed is the core source of all agricultural potential. Other agricultural inputs merely assist in unlocking the inherent yield potential of the seed. If fertilizer usage contaminates the soil, why blame the seed? Moreover, the claim that the native varieties are always disease- and pest-resistant is also untrue. If it were true, the yield of rice in Bengal wouldn't have plummeted due to the brown spot disease in 1942. On the contrary, most of the currently popular HYVs are tolerant to multiple pests and diseases. The propaganda against HYV rice ignores these facts and tries to paint a misleading picture.

A Look at the disappearance of heirloom rice

The loss of diversity in rice began long before the advent of HYV rice. In fact, it started from the very beginning of the domestication of rice. Whenever a superior variant of rice has emerged, farmers have readily moved away from cultivating the inferior ones in favor of the better variant. It happened during the process of domestication as also afterword. In the Book "Rice diversity in west Bengal published by the West Bengal Biodiversity Board in 2007, it was observed that many traditional varieties found in the fields of two 24 parganas districts were not listed in W. W. Hunter's 1870 catalog of cultivated rice for those districts. Likewise, many varieties listed by Hunter were no longer found in the recent survey. The missing traditional varieties were undoubtedly outperformed by the newer varieties introduced later. The replacement of one variety of indigenous rice with another more productive variety by farmers reflects their keen desire for higher yield. This is only natural. Agriculture is their livelihood. If the crops produced in the field are consumed entirely at home, how will he go to the market to sell them? How will his household run? The more rice a farmer can produce beyond his household needs from his own land, the more comfortable his life will be. This pursuit of better yields has driven farmers since ancient times and continues to do so today. When the initially used indigenous was found low-yielding, it was replaced with improved indigenous rice varieties, and subsequently, HYV rice was introduced. The rapid adoption of HYV rice, replacing traditional varieties was driven primarily by the promise of harvesting more rice. This ensured a larger surplus for the market. The proliferation of HYV rice was thus a natural outcome as it endorsed higher income for the farmers. The research findings published in the Journal of Agriculture and Environment in 2020 corroborate this fact.

Although the promotion of HYV rice varieties has largely edged out traditional varieties from the fields, they have not vanished entirely. These cherished heirloom strains still flourish in specific ecological niches where HYV rice fails to prevail. Their survival is owed to their superior taste and aroma, or their remarkable resilience to fragile environments. The next phase involves the delicate extraction of these resilient traits from traditional varieties into HYV rice, enhancing its qualities. Successes such as Swarna sub1, Jarava etc. bear testament to these efforts. As this endeavor progresses the cultivation of traditional rice will gradually diminish, surviving in pockets only as commercially viable varieties. This seems an inevitable trajectory. However, even if they fade from the fields, they will not be lost forever. They will be meticulously conserved in repositories like NBPGR and IBPGR, safeguarding their legacy and essence for the generations to come.

Those advocating for the widespread cultivation of traditional rice over HYV rice should consider India's 107th position out of 120 countries in the Global Hunger Index 2022.The same year's Global Food Policy Report forewarns that by 2030, India will host the largest number of hungry people in the world, totaling 17 million. According to FAO, despite the continuous rise in annual rice production and yield in India over the past three decades – registering a 2.4% increase in production and a 1.9%increase in yield – the growth is still insufficient to meet escalating demand. To eradicate huger and achieve self-sufficiency in rice production in the coming days, we must not only rely on HYV rice but also develop and adopt even more advanced, ultra-high yielding rice varieties that surpass the yield limits of HYV strains.

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