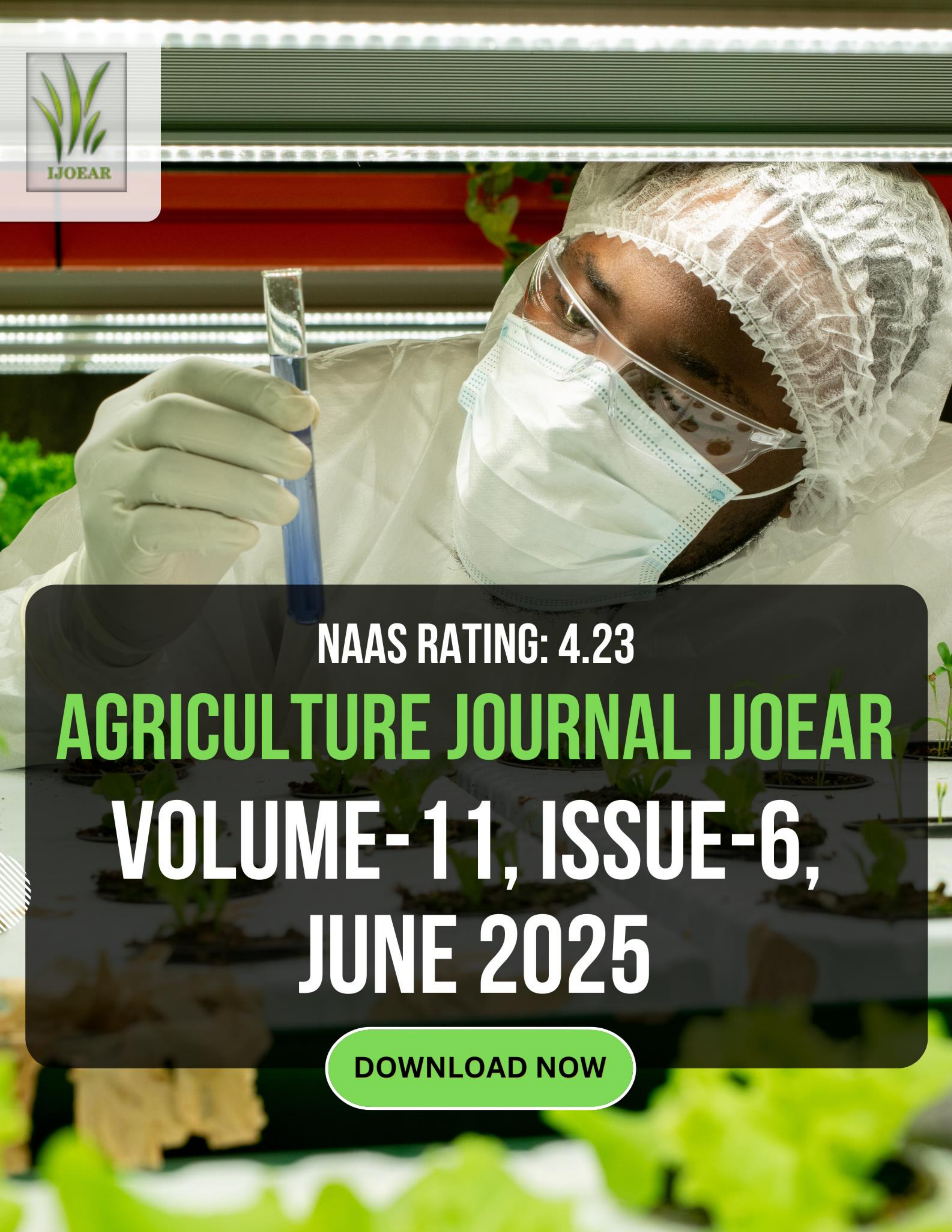
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Preface

We would like to present, with great pleasure, the inaugural volume-11, Issue-6, June 2025, of a scholarly journal, *International Journal of Environmental & Agriculture Research*. This journal is part of the AD Publications series *in the field of Environmental & Agriculture Research Development,* and is devoted to the gamut of Environmental & Agriculture issues, from theoretical aspects to application-dependent studies and the validation of emerging technologies.

This journal was envisioned and founded to represent the growing needs of Environmental & Agriculture as an emerging and increasingly vital field, now widely recognized as an integral part of scientific and technical investigations. Its mission is to become a voice of the Environmental & Agriculture community, addressing researchers and practitioners in below areas.

Environmental Research:

Environmental science and regulation, Ecotoxicology, Environmental health issues, Atmosphere and climate, Terrestric ecosystems, Aquatic ecosystems, Energy and environment, Marine research, Biodiversity, Pharmaceuticals in the environment, Genetically modified organisms, Biotechnology, Risk assessment, Environment society, Agricultural engineering, Animal science, Agronomy, including plant science, theoretical production ecology, horticulture, plant, breeding, plant fertilization, soil science and all field related to Environmental Research.

Agriculture Research:

Agriculture, Biological engineering, including genetic engineering, microbiology, Environmental impacts of agriculture, forestry, Food science, Husbandry, Irrigation and water management, Land use, Waste management and all fields related to Agriculture.

Each article in this issue provides an example of a concrete industrial application or a case study of the presented methodology to amplify the impact of the contribution. We are very thankful to everybody within that community who supported the idea of creating a new Research with *IJOEAR*. We are certain that this issue will be followed by many others, reporting new developments in the Environment and Agriculture Research Science field. This issue would not have been possible without the great support of the Reviewer, Editorial Board members and also with our Advisory Board Members, and we would like to express our sincere thanks to all of them. We would also like to express our gratitude to the editorial staff of AD Publications, who supported us at every stage of the project. It is our hope that this fine collection of articles will be a valuable resource for *IJOEAR* readers and will stimulate further research into the vibrant area of Environmental & Agriculture Research.

Mukesh Arora
(Managing Editor)

Dr. Bhagawan Bharali
(Chief Editor)

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Combining Ability Analysis for Seed Yield per Plant and its Contributing Traits in Castor (*Ricinus communis* L.)

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***Abstract*—** *A line × tester analysis of twenty four hybrids developed by crossing four lines and six testers were carried out under three diverse environments. The components of genetic variance were estimated from the analysis of variances for combining ability of different characters for each environment and pooled also. The analysis of variance for combining ability individual as well as pooled over environments revealed that mean squares due to lines and testers were significant for most the characters, Line × Tester was significant for all the characters except seed yield per plant and estimated genetic variance due to GCA and SCA was non-significant for all the characters in pooled over environments. The ratio of* σ^2gca/σ^2sca *was less than unity which revealed the predominant role of non-additive gene action for inheritance of the traits for days to flowering, days to maturity, number of nodes up to primary raceme, effective length of primary raceme, seed yield per plant and 100-seed weight. Therefore, heterosis breeding may be suggested to exploit hybrid vigour and recombinant in* F_2 *and subsequent generations for isolating lines for seed yield and its contributing traits. The line SKP 126 and tester SKI 420 were found as good general combiners for the yield attributing characters in pooled over the environments. Among the crosses, best three specific combiner were SKP 120 × SKI 420, SKP 126 × SKI 357 and SKP 106 × SKI 412 for seed yield per plant and its contributing traits.*

***Keywords*— Combining ability, Gene action, GCA, SCA.**

I. INTRODUCTION

Castor (*Ricinus communis* L.), a monotypic species in the spurge family (Euphorbiaceae) with 2n = 20 chromosomes, is an important non-edible oilseed crop. India is one of the largest producers of non-edible oilseeds in the world. It is also known as the castor-oil plant, higuerito, higuerillo, palma, christi, carrapateira and many other common names i.e. arindi, divela. In mature castor seed, 90-95% of the total seed protein is in the endosperm. In the endosperm, crystalloid proteins comprise 70 to 80% of the total protein and are insoluble in water. It has the approximate fatty acid composition of ricinoleic acid (87%), oleic acid (7%), linoleic acid (3%), palmitic acid (2%) and stearic acid (1%), with trace amounts of dihydroxystearic acid. Ricinoleic acid available in castor bean oil has its proven effectiveness in inhibiting the growth of various species of viruses, bacteria, yeasts and moulds. Ricin, a poisonous substance found in castor, is state-of-art tool in neurobiology for selectively destroying neuronal populations (De-La-Cruz *et al*., 1995).

The combining ability helps in partitioning the total genetic variation into general combining ability of parents and specific combining ability of crosses, which is useful to assess the nature and magnitude of gene action controlling different characters. The efficient partitioning of genetic variance into its components *viz.*, additive and non-additive will help in formulating an effective and sound breeding programme. The cases where the cost of hybrid seed are of greater importance, the use of additive gene effects of parents could be used to retain the vigour in subsequent segregating generations to develop stable varieties, while non-additive gene effects respond to heterosis breeding. Among the several methods, Line x Tester analysis of combining ability is one of the important biometrical tools to identify the promising male and female parental lines as well as to obtain necessary data on the expression of heterosis for the future. Line x Tester analysis provides information for combining ability. The study of general combining ability (GCA) effects help in selection of superior parents and specific combining ability (SCA) effects for superior hybrids. With the help of this information it gives overall genetic pictures of the materials under investigation.

II. MATERIALS AND METHODS

The present investigation was carried out using Line × Tester design for ten characters at three locations during *kharif* 2023 to generate information on combining ability and for seed yield and its components traits. The experimental materials consisted of 35 genotypes; comprising of 24 hybrids developed by using Line × Tester design, 4 lines and 6 testers, with standard check hybrid GCH 8. All the genotypes were evaluated in Randomized Block Design (RBD) replicated thrice in three environments formed by different locations and observations were recorded on ten characters *viz.,* Days to flowering, Days to maturity, Plant height up to primary raceme (cm), Number of nodes up to primary raceme, Effective length of primary raceme (cm), Number of capsules on primary raceme, Effective branches per plant, Seed yield per plant (g), 100-seed weight (g) and Oil content (%). The mean values on these ten characters were recorded in all the three locations of experimentation and the pooled mean values were subjected to statistical analysis.

III. RESULTS AND DISCUSSIONS

The analysis of variance for combining ability carried out for ten characters under investigation is presented in Table.1 for pooled over three environments. The analysis of variance for combing ability revealed that variations due to lines used as females were significant for all characters.

TABLE 1
ANALYSIS OF VARIANCE FOR COMBINING ABILITY, ESTIMATES OF COMPONENTS OF VARIANCE AND THEIR RATIOS FOR DIFFERENT CHARACTERS IN CASTOR FOR POOLED OVER THREE ENVIRONMENTS

Source of variation	d. f.	Days to flowering	Days to maturity	Plant height up to primary raceme	Number of nodes up to primary raceme	Effective length of primary raceme
Environments	2	1051.27 **	2624.48 **	4410.62 **	87.24 **	363.15 **
Replications	2	7.48	35.93 *	107.33	7.82	91.61
Line (L)	3	45.66 **	113.14 **	3489.68 **	53.97 **	1276.47 **
Tester (T)	5	78.29 **	128.39 **	3689.87 **	38.39 **	74.18
Line × Tester	1	318.94 **	818.94 **	32978.52 **	311.15 **	998.51 **
Line × Environment	6	1.52	6.78	24.43	8.66 **	170.26 **
Tester × Environment	10	7.13 *	9.33	41.2	0.48	75.61 *
L × T × Environment	2	7.03	3.56	235.11 *	6.48	151.23 *
σ^2gca	-	1.68	2.9	66.4	0.06	26.97
σ^2sca	-	2.97	6.2	30.36	0.12	40.48
σ^2gca/ σ^2sca	-	0.57	0.47	2.19	0.47	0.67
Pooled Error	138	3.41	8.87	75.8	2.67	40.48

TABLE 1 CONTINUE

Source of variation	d. f.	Number of capsules on primary raceme	Effective branches per plant	Seed yield per plant	100-seed weight	Oil content
Environments	2	485.40 **	131.88 **	11472.38 **	57.04 **	3.33 *
Replications	2	33.13	5.27 *	2709.54	0.52	1.72
Line (L)	3	939.25 **	18.86 **	10086.16 **	27.24 **	4.77 **
Tester (T)	5	247.54 **	46.22 **	3512.69	82.58 **	57.19 **
Line × Tester	1	4135.61 **	21.84 **	439.56	133.98 **	65.94 **
Line × Environment	6	86.29	2.94 *	1971.19	2.23	0.18
Tester × Environment	10	172.90 **	3.15 **	232.68	2.62 *	0.15
L × T × Environment	2	300.73 *	12.21 **	90.5	3.61 *	0.02
σ^2gca	-	22.81	3.38	2266.05	0.8	1.52
σ^2sca	-	17.23	1.64	2643.44	1.41	1.27
σ^2gca/ σ^2sca	-	1.32	2.06	0.86	0.56	1.19
Pooled Error	138	69.89	1.45	1656.91	1.21	0.51

,** Significant at $P \leq 0.05$ and $P \leq 0.01$ levels of probability, respectively

The variations due to testers mean square were significant for all the traits except effective length of primary raceme and seed yield per plant. The analysis of variance for combing ability also revealed that variations due to line × tester were significant for all the traits (except for seed yield per plant). This data suggested the importance of gene action in the inheritance of traits under investigation. The line × environment interaction variance was found to be significant for number of nodes up to primary raceme, effective length of primary raceme and effective branches per plant. Similarly, testers responded differently to array of the environments as the variance due to testers × environments interaction was significant for most of the characters like days to flowering, effective length of primary raceme, number of capsules on primary raceme, effective branches per plant and 100 seed weight.

Significance of hybrids × environments interaction variance revealed that performance of hybrids varied over the environments for the trait under study except days to flowering, days to maturity, number of nodes up to primary raceme, seed yield per plant and oil content. Genetic variance due to gca (σ^2gca) and sca (σ^2sca) was non-significant for all the characters in pooled over environments. The ratio of σ^2gca/σ^2sca was greater than unity which revealed the predominant role of additive gene action for inheritance of the traits in pooled over environments for plant height up to primary raceme, number of capsules on primary raceme, effective branches per plant and oil content. The ratio of σ^2gca/σ^2sca was less than unity which revealed the predominant role of non-additive gene action for inheritance of most of the traits in pooled over environments for days to flowering, days to maturity, number of nodes up to primary raceme, effective length of primary raceme, seed yield per plant and 100 seed weight.

The similar results for ratio of σ^2gca/σ^2sca, for additive gene action were reported by Rajani *et al.* (2015), Sapovadiya *et al.* (2015b), kavani *et al.* (2016), Delvadiya *et al.* (2018), Panera *et al.* (2018) and Mohanty *et al.* (2021). For non-additive gene action different traits of castor under study showed similar results as reported by Ramesh *et al.* (2013), Rajani *et al.* (2015), Sapovadiya *et al.* (2015b), Delvadiya *et al.* (2018), Dube *et al.* (2018), Panera *et al.* (2018) and Ramya *et al.* (2018).

TABLE 2
ESTIMATES OF GENERAL COMBINING ABILITY EFFECTS OF LINES AND TESTERS IN POOLED OVER ENVIRONMENT

Sr. No.	Parents	DF	DM	PH	NN	LP	NC	EB	SY	SW	OC
Lines											
1	SKP 84	0.14	0.54	-4.53 **	-0.15	-0.13	0.11	-2.44 **	12.88 *	1.00 **	-0.56 **
2	SKP 106	-0.06	0.57	0.91	0.27	2.66 **	1.65	0.13	22.31 **	-1.12 **	0.54 **
3	SKP 120	-1.15 **	-1.87 **	-3.95 **	-0.36	-8.31 **	-6.86 **	0.09	-74.53 **	0.06	0.39 **
4	SKP 126	1.07 **	0.76	7.58 **	0.24	5.78 **	5.10 **	2.23 **	39.35 **	0.06	-0.36 **
S. Em. ±		0.25	0.41	1.18	0.22	0.87	1.14	0.16	5.54	0.15	0.09
Testers											
1	JC 12	2.86 **	3.66 **	-7.78 **	0.24	-4.08 **	-6.05 **	-2.06 **	-13.23	1.75 **	1.52 **
2	SKI 357	-2.01 **	-2.26 **	-12.01 **	-0.55 *	-3.50 **	-2.84 *	0.38	-24.25 **	-1.20 **	-1.34 **
3	SKI 403	-1.09 **	0.13	8.20 **	-0.22	-0.27	-0.61	-0.13	-48.33 **	-0.09	-2.10 **
4	SKI 407	-0.73 *	-2.76 **	17.89 **	0.39	1.23	0.29	-1.06 **	-4.99	-0.29	-0.99 **
5	SKI 412	-0.34	0.41	-1.86	0.35	-0.01	0.90	-0.25	12.80	-0.18	2.71 **
6	SKI 420	1.30 **	0.82	-4.44 **	-0.21	6.63 **	8.31 **	3.11 **	77.99 **	0.00	0.19
S. Em. ±		0.31	0.50	1.45	0.27	1.06	1.39	0.20	6.78	0.18	0.12

***, ** Significant at P ≤ 0.05 and P ≤ 0.01 levels of probability, respectively**

DF – Days to flowering, DM – Days to maturity, PH – Plant height upto primary raceme, NN – Number of nodes upto primary raceme, LP – Effective length of primary raceme, NC – Number of capsules on primary raceme, EB – Effective branches, SY – Seed yield per plant, SW – 100 seed weight, OC – Oil content

The estimate of GCA effect indicated that the parents SKP 120 and testers SKI 357 were good general combiners for earliness (Table 2) i.e. for days to flowering, days to maturity, plant height upto primary raceme and number of nodes up to primary raceme. Good general combiners for these traits were also reported by Mohanty *et al*. (2021). Parental lines SKP 126 and SKI 420 were good combiners for effective length of primary raceme and number of capsules on primary raceme and effective branches per plant. On pooled over environments basis the line SKP 84, SKP 106 and SKP 126, where tester SKI 420 were recorded to have significantly positive gca effects for the trait. The results were in correspondence to Panera *et al.* (2018), Delvadiya *et al*. (2018) and Yamanura *et al*. (2020). The line SKP 84 and testers JC 12 were found to have significant positive gca effects for the 100 seed weight. Where, for oil content lines SKP 106 and SKP 120 and testers JC 12 and SKI 412 were found to have significant positive gca effects (Table 2). Similar kind of research were also found by Kavani *et al*. (2016) and Ramya *et al*. (2018).

Hybrids SKP 84 × JC 12, SKP 106 × SKI 412 and SKP 120 × SKI 357, SKP 120 × SKI 403 were found significant negative sca for days to flowering and days to maturity (Table 3). For days to flowering and days to maturity Sridhar *et al.* (2008) and Yamunura *et al*. (2020) also reported the same results for hybrids they studied. SKP 120 × SKI 412, SKP 126 × SKI 403 and SKP 106 × SKI 420 found negative significant sca effect in pooled over environments. Out of total twenty four hybrids, two hybrids SKP 120 × SKI 420 and SKP 84 × JC 12 found positive significant sca effect in pooled over environments for effective length of primary raceme and number of capsules up to primary raceme (Table 3). For effective branches per plant and seed yield per plant, four hybrids *viz.*, SKP 120 × SKI 420, SKP 126 × SKI 357, SKP 84 × SKI 412 and SKP 106 × SKI 412 found positive significant sca effect in pooled over environments. Three hybrids exhibiting highest positive significant sca effect for oil content were SKP 120 × SKI 407, SKP 126 × JC 12 and SKP 126 × SKI 412 (Table 3).

TABLE 3
ESTIMATES OF SPECIFIC COMBINING ABILITY EFFECTS OF HYBRIDS IN POOLED OVER ENVIRONMENTS

Sr. No.	Hybrids	DF	DM	PH	NN	LP	NC	EB	SY	SW	OC
1	SKP 84 × JC 12	-2.12 **	-2.84 **	0.03	0.38	7.11 **	5.69 *	0.50	13.60	0.35	0.30
2	SKP 84 × SKI 357	-0.14	1.52	-5.17	-0.14	5.32 *	5.07	-0.64	-11.22	-0.97 **	-0.61 *
3	SKP 84 × SKI 403	1.38 *	2.24 *	-1.05	0.11	-6.23 **	-2.65	-1.11 **	14.00	-0.22	-0.14
4	SKP 84 × SKI 407	-0.76	-0.87	3.01	-0.91	-1.15	-3.23	0.59	17.29	1.59 **	-1.10 **
5	SKP 84 × SKI 412	0.41	1.41	2.65	1.21 *	-4.05	-3.66	2.25 **	30.94 *	0.32	0.74 **
6	SKP 84 × SKI 420	1.22 *	-1.45	0.53	-0.63	-1.00	-1.21	-1.60 **	-64.62 **	-1.09 **	0.82 **
7	SKP 106 × JC 12	0.42	-0.66	7.78 **	0.06	2.49	2.23	1.23 **	38.29 **	0.37	-1.06 **
8	SKP 106 × SKI 357	2.51 **	3.26 **	6.04 *	0.26	-2.80	-3.00	0.10	-58.59 **	-0.51	0.99 **
9	SKP 106 × SKI 403	1.14	2.20 *	0.15	0.54	0.03	1.75	-0.44	-56.72 **	0.49	0.58 *
10	SKP 106 × SKI 407	-0.55	-1.13	-2.29	-0.11	7.41 **	5.05	-1.52 **	25.92	-3.09 **	-0.02
11	SKP 106 × SKI 412	-1.94 **	-3.41 **	-5.46	-0.96	4.74 *	1.96	0.37	51.66 **	1.53 **	0.04
12	SKP 106 × SKI 420	-1.58 *	-0.27	-6.22 *	0.22	-11.87 **	-7.99 **	0.26	-0.57	1.21 **	-0.52 *
13	SKP 120 × JC 12	2.63 **	2.45 *	-5.67	0.37	-11.67 **	-8.81 **	-1.42 **	-55.67 **	-0.43	-0.63 **
14	SKP 120 × SKI 357	-1.18	-3.85 **	0.35	-0.43	0.53	-0.85	-0.65	3.37	0.68	-0.27
15	SKP 120 × SKI 403	-2.10 **	-3.57 **	7.22 *	-0.52	4.26	0.47	0.83 *	38.83 **	-0.23	0.07
16	SKP 120 × SKI 407	1.54 *	3.76 **	-1.83	0.48	-1.66	2.99	1.37 **	-16.34	0.85 *	2.34 **
17	SKP 120 × SKI 412	-1.29 *	0.15	-7.70 **	-0.13	-1.41	-0.82	-1.58 **	-66.63 **	-0.95 *	-1.79 **
18	SKP 120 × SKI 420	0.40	1.07	7.63 **	0.23	9.95 **	7.03 *	1.44 **	96.43 **	0.09	0.28
19	SKP 126 × JC 12	-0.93	1.05	-2.15	-0.80	2.07	0.90	-0.32	3.78	-0.29	1.39 **
20	SKP 126 × SKI 357	-1.18	-0.93	-1.22	0.32	-3.05	-1.21	1.19 **	66.43 **	0.80 *	-0.11
21	SKP 126 × SKI 403	-0.43	-0.87	-6.32 *	-0.12	1.95	0.43	0.72	3.89	-0.04	-0.50 *
22	SKP 126 × SKI 407	-0.24	-1.76	1.11	0.55	-4.61 *	-4.81	-0.44	-26.88 *	0.64	-1.22 **
23	SKP 126 × SKI 412	2.82 **	1.85	10.51 **	-0.12	0.71	2.52	-1.05 **	-15.96	-0.90 *	1.01 **
24	SKP 126 × SKI 420	-0.04	0.66	-1.95	0.18	2.91	2.18	-0.10	-31.25 *	-0.21	-0.58 *

IV. CONCLUSION

The estimates of genetic variance revealed preponderance of non-additive gene action for inheritance of days to flowering, days to maturity, number of nodes up to primary raceme, effective length of primary raceme, number of capsules on primary raceme, seed yield per plant and 100 seed weight. Therefore, population improvement by advancing hybrids involved in both good general combiner parents may be followed along with heterosis breeding; thus, superior recombinants may be isolated for future breeding programmes. The lines SKP 126 and tester SKI 420 were found as good general combiners for the yield-attributing characters in pooled over the environments. Therefore, these parents would be of immense value for the simultaneous improvement of desirable agronomical/morphological attributes in addition to heterosis breeding. Among the crosses, the best three specific combiner hybrids were SKP 120 × SKI 420, SKP 126 × SKI 357 and SKP 106 × SKI 412 for seed yield per plant. They also exhibited significant and desirable SCA effects for other component characters, justifying seed yield phenomena as a dependent complex character and is the outcome of direct and indirect effects of different component characters.

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Analysis of Soil Damage on Dry Land Based on Geographic Information System in Sawan Sub-Distric, Buleleng Regency

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Abstract— *Sawan sub-district is one of the sub-districts in Buleleng Regency, part of which is dry land with an area of 3,144.06 ha. Dry land productivity in Sawan Sub-district is vulnerable to decline because land management is still not in accordance with conservation principles. The purpose of the study was to determine the potential for soil damage, the status of soil damage, the distribution of soil damage, and the direction of soil damage management on dry land in Sawan District. The method in this study used a comparative descriptive method. Parameters observed in the field include surface rock and soil solum depth while parameters analyzed in the laboratory are content weight, fraction composition, permeability, total porosity, pH, DHL, number of microbes and C-organic content. Based on the overlay of land use map, rainfall map, slope map, and soil type map using geographic information system, 17 SLH were obtained. The results showed two classes of potential soil damage, namely the potential for mild soil damage in Bebetin Village, Suwug Village, Sekumpul Village with a distribution percentage of 64.7% and the potential for moderate damage in Sudaji Village, Giri Emas Village, Lemukih Village, Bebetin Village and Sekumpul Village with a distribution percentage of 29.4%. Soil damage status classified as light in Bebetin Village, Giri Emas Village, Lemukih Village, Sekumpul Village and Sudaji Village with a distribution percentage of 64.7%, no factors causing soil damage status were found so that it is classified as good. Lightly damaged soil status with limiting factors of permeability is found in Sudaji Village, Suwug Village and Lemukih Village with a distribution percentage of 29.4%. Lightly damaged soil status with limiting factors of content weight, pH, and permeability is found in Bungkulan Village with a distribution percentage of 5.8%. Recommendations for improvement are the addition of organic matter and soil management can be done by planting cover crops or by crop rotation*.

Keywords— Potential For Land Damage, Status of Land Damage, Dry Land, Sawan District.

I. INTRODUCTION

Soil is the provider of all needs in supporting plant growth and production. Soil is one of the growing mediums of plants, both plants in dry and wet land farms. The soil always undergoes changes caused by materials from the soil itself or materials from outside the soil (Suripin, 2002). Drylands are lands that are never inundated with water throughout the year. It relies on rainwater as its main source of water and rarely experiences permanent inundation. Drylands are used for moorland, mixed gardens, plantations, forests and so on. Management of biomass production that does not pay attention to conservation principles, such as the selection of vegetation types on agricultural land and the use of synthetic chemicals that exceed the recommended limit, can cause soil damage. This damage is characterized by changes in soil properties that exceed the threshold of soil damage criteria, thus reducing the ability of soil to support biomass production (Government Regulation No. 150 of 2000).

Based on data from the Central Bureau of Statistics, Sawan District shows a decrease in productivity from year to year. Some dryland commodities that have decreased are cayenne pepper and shallots. Cayenne pepper productivity from 2020 to 2021 has decreased by 71 tons and shallot productivity from 2020 to 2021 has decreased by 260 tons (BPS Kecamatan Sawan, 2023). Based on data from the Directorate General of Horticultural Crops in 2015, the target production of cayenne pepper plants is 9-20 tons/ha and for shallot plants is 18-20 tons/ha. The decline is thought to be caused by soil damage and lower soil fertility levels, so an assessment of the potential and status of dryland soil damage and land management in Sawan District, Buleleng Regency is needed.

II. MATERIAL AND METHODS

The research was conducted from June to December 2024, on dry land in Sawan District, Buleleng Regency. Analysis of soil physical, chemical, and biological properties was carried out at the Soil and Environment Laboratory, Faculty of Agriculture, Udayana University, Denpasar.

The materials used in the research were the map of Sawan Subdistrict, soil type map with a scale of 1:100,000, land use map with a scale of 1:100,000, slope map with a scale of 1:100,000, rainfall data, Rupa Bumi Indonesia (RBI) map, soil as a sample analysis, and chemicals for sample analysis in the laboratory.

The tools used were laptop, QGIS 3.24.1 application, GPS (Geographic Positioning System), abney level, sample ring, soil drill, field knife, plastic, pH meter, 2 mm sieve, measuring cup, volume pipette, rubber suction, detrition device, distillation device, boiling flask, titration device, petri dish, pycnometer, test tube, filter paper, scale, pipette, The research was conducted using a comparative descriptive method with field surveys, laboratory analysis and scoring of potential soil damage based on Permen LH No. 20 of 2008. The status of soil damage in this study was determined based on the standard criteria for soil damage (Permen LH No. 07, 2006). Kartini et al. (2023) have conducted research in the Baturiti District area, especially on dry land based on the same approach. Physical parameters are soil depth, surface rock, content weight, fraction composition, permeability, total porosity. Chemical parameters, namely pH and DHL, and biological parameters, namely the number of microbes, were analyzed in the laboratory. The damage status was determined based on the critical threshold set in Government Regulation No. 150 of 2000.

The research implementation consisted of several stages, namely: 1) literature study stage, 2) determination of homogeneous land units, 3) field survey and sampling, 4) laboratory analysis, 5) data analysis and evaluation of soil damage status, 6) determination of damage status and making maps of soil damage distribution. Homogeneous land units of the research area are presented in Table 1 and Figure 1.

TABLE 1
HOMOGENEOUS LAND UNITS OF THE STUDY AREA

No	SLH	Land Use	Slopes (%)	Soil Type	Extensive (ha)
1	Sudaji Village	Field	25-40	Oxisol	145.5
2	Bebetin Village	Field	8-15	Oxisol	544.57
3	Giri Emas Village	Field	0-8	Entisol	595.6
4	Lemukih Village	Field	25-40	Entisol	153.2
5	Lemukih Village	Field	8-15	Entisol	1,001.83
6	Bungkulan Village	Field	0-8	Entisol	50.52
7	Galungan Village	Field	25-40	Oxisol	164.21
8	Bebetin Village	Mixed Garden	8-15	Oxisol	88.75
9	Suwug Village	Mixed Garden	0-8	Entisol	149.47
10	Lemukih Village	Mixed Garden	25-40	Entisol	249.19
11	Suwug Village	Mixed Garden	8-15	Entisol	411.81
12	Lemukih Village	Mixed Garden	15-25	Entisol	70.63
13	Bebetin Village	Mixed Garden	8-15	Oxisol	85.11
14	Sekumpul Village	Mixed Garden	15-25	Oxisol	51.24
15	Sekumpul Village	Mixed Garden	15-25	Entisol	321.93
16	Sudaji Village	Mixed Garden	25-40	Oxisol	24.82
17	Sekumpul Village	Mixed Garden	>40	Oxisol	37.51
	Total area of the research area				**3,144.06**

Source: Spatial data Analysis

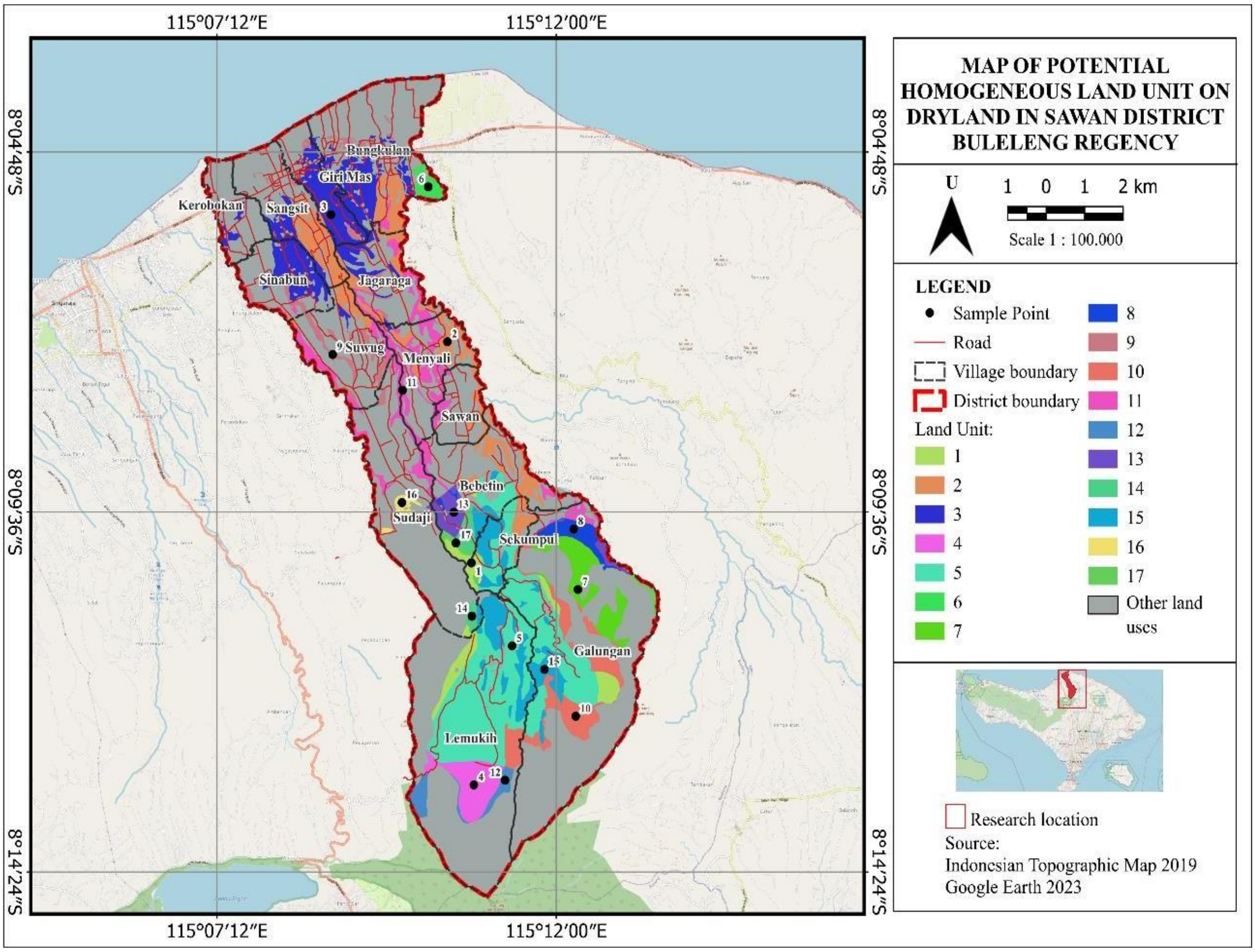

FIGURE 1: Map of dry land homogeneous land units in Sawan District

2.1 Determination of Potential Soil Damage:

The score of potential soil damage on dry land is determined based on the results of the analysis with the scoring method on each parameter. The score and potential for dryland soil damage in Sawan Subdistrict are determined based on the results of multiplying the rating values of land use, slope, soil type, and rainfall by the weight value. The distribution map of potential soil damage is obtained based on the value of the results of the overlay map of slope, soil type, land use and rainfall. Classes of potential soil damage are presented in Table 2.

TABLE 2
POTENTIAL SOIL DAMAGE CLASS

Symbol	Potensi Kerusakan Tanah	Weighting Score
PR.I	Very Light	<15
PR.II	Light	15-24
PR.III	Medium	25-34
PR.IV	High	35-44
PR.V	Very High	45-50

Source: Regulation of the Minister of Environment Number 20 of 2008

2.2 Soil Damage Status Analysis:

Physical, chemical, and biological properties of soil based on soil damage parameters based on the standard criteria for soil damage (PP No. 150/2000) were analyzed by means of field observations and laboratory analysis. The analyzed parameters are presented in Table 3.

TABLE 3
SOIL DAMAGE EVALUATION PARAMETER

No.	Parameters	Symbol	Ambang Kritis (PP 150/2000)
1	Soil Thickness	s	<20 cm
2	Surface Rock	b	>40%
3	Fraction Composition	f	<18% koloid; >80% pasir kuarsitik
4	Content Weight	d	>1,4 g/cm^3
5	Total Porosity	v	<30 %; >70 %
6	Degree of Water Smoothness	p	<0,7 cm/jam >8,0 cm/jam
7	pH (H2O) 1:2,5	a	<4,0;>7,0
8	Electrical Conductivity/DHL	c	>4,0 mS/cm
9	Microbial Count	m	$<10^2$ cfu/g soil

Source: Government Regulation Number 150 of 2000

2.3 Determination of Soil Damage Status:

Determination of soil damage status is done by scoring based on the relative frequency (%) of each parameter used. The relative frequency of soil damage is the percentage value of soil damage based on the comparison of the number of soil samples classified as damaged to the total number of samples observed and analyzed in each parameter (Permen LH No. 20, 2008). The score value of all parameters is used to determine the category of soil damage status. Soil damage status is categorized into five, namely not damaged (N), lightly damaged (R.I), moderately damaged (R.II), severely damaged (R.III), and very severely damaged (R.IV).

III. RESULTS AND DISCUSSION

3.1 Potential Land Damage In Sawan Sub-District:

Soil Damage Potential on dry land in the research area based on the results of the analysis with the scoring method, there are two classes of potential damage to dry land soils, namely the class of light and medium damage potential. The potential for light damage to dry land in Sawan Sub-district with the symbol PR.II is scattered in SLH 2, 8, 9, 11, 13 and 14 located in Bebetin Village, Suwug Village and Sekumpul Village spread over an area of 1,330.95 ha with a percentage of 35.3%. The potential for moderate damage with the symbol PR.III is scattered in SLH 1, 3, 4, 5, 6, 7, 10, 12, 15 16 and 17 located in Sudaji Village, Giri Emas Village, Galungan Village, Lemukih Village, Bungkulan Village, Bebetin Village and Sekumpul Village spread over an area of 1,813.11 ha with a percentage of 64.7%. Scores and classes of potential dryland soil damage in Sawan Sub-district are presented in Table 4.

TABLE 4
SCORE AND POTENTIAL SOIL DAMAGE

No	Score	Potential Land Damage	Symbol	Area (ha)
1	15-24	Light	PR.II	1,330,95
2	25-34	Medium	PR.III	1,813,11

Source: Regulation of the Minister of Environment Number 20 of 2008

The class of light soil damage potential in the study area is influenced by land use and slope. This potential for minor damage is different on each dry land in all SLH, 17 sample points have 2 types of land use, namely mixed gardens and fields, rainfall of 1000-2000 mm/year, soil types yellowish brown Latosol, gray brown Regosol, brown Regosol. However, there are differences in the slope class of each SLH.

Uncontrolled land management and utilization can cause soil damage which has an impact on the decline in soil function and quality (Dela Rosa, 2005). Soil damage will result in damage to the basic properties of the soil, both physical, chemical, and biological properties of the soil, so that it can interfere with the process of plant growth. The inhibition of plant growth will result in reduced biomass production (Arisandi et al., 2015).

The rainfall situation in the dryland is 1000-2000 mm/year. Rainfall intensity and slope slope produce an influence that is directly proportional to soil erosion which has an impact on the potential for soil damage to be higher (Sitepu et al., 2017). Soil erosion has a major negative impact on changes in soil physical properties including soil structure, soil texture, soil moisture content, and soil content density over a long period of time (Trigunasih and Saifulloh, 2023). Other studies have found that the potential for soil damage is closely related to unproductive land areas due to the impact of eruptions and landslides (Trigunasih et al., 2023; Diara et al., 2023). In land management, it is important to pay attention to this factor to optimize soil conservation and prevent land degradation. High slope can cause a decrease in soil pH due to erosion which increases the loss of soil nutrients and bases (Septiaji et al., 2024). The first step in overcoming soil damage is to inventory the potential for soil damage in an area. Inventory can be done by spatial mapping, especially of potential soil damage factors (Lias, 2021).

3.2 Status of Soil Damage in Sawan Sub-District:

The results of the analysis of soil physical, chemical and biological properties were matched with the standard criteria for soil damage in Government Regulation No. 150 of 2000, there were three parameters that exceeded the critical threshold of soil damage, namely content weight, pH and permeability in several SLH. Based on the relative frequency, the content weight parameter obtained a damage of 6%, the pH parameter obtained a damage of 6% and the permeability parameter obtained a damage of 35%. The total score obtained from the relative frequency of damaged soil on dry land in Sawan Subdistrict is 2 which indicates that the area has a lightly damaged soil damage status. The determination of the results of the relative frequency of damaged soil and soil damage status is presented in Table 5.

TABLE 5
RESULT OF ACCUMULATIVE SCORE OF SOIL DAMAGE

No.	Parameter	Relative Frequency of Damaged Tanah	Skor	Status
1	Soil Thickness	0	0	Not Damaged
2	Surface Rock	0	0	Not Damaged
3	Fraction Composition	0	0	Not Damaged
4	Weight Content	6	0	Not Damaged
5	Total Porosity	0	0	Not Damaged
6	Permeability	35	2	Not Damaged
7	pH (H2O) 1:2,5	6	0	Not Damaged
8	Electrial Conductivity	0	0	Not Damaged
9	Microbial Count	0	0	Not Damaged
Total Score			2	Mildly Damaged

Source: Government Regulation Number 150 year 2000

The results of the analysis show that dryland in Sawan Subdistrict has a lightly damaged status with the factors causing damage are content weight, pH and permeability. Weight content becomes a damage factor when it is higher than the critical threshold of soil damage $(1,4\ g/\mathrm{cm}^3)$. High weight contents indicate soil compaction, which can inhibit plant root growth, reduce water infiltration, and limit soil aeration (Brady & Weil, 2016).

Compacted soil has fewer and smaller pores, making it difficult for plant roots to penetrate, roots tend to grow shallowly and spread laterally rather than penetrating deeper in search of water and nutrients. As a result, plants are more susceptible to drought and nutrient deficiencies as they cannot access resources in deeper soil layers.

Based on the data from the analysis of soil damage status, permeability in some SLH is classified as damaged with a percentage of 17.6%. Soil permeability affects the ability of soil to pass water, which is important to ensure water availability for plants (Hura, 2024). Low permeability can be caused by soil compaction, high clay content, or lack of organic matter. As mentioned earlier, the addition of organic matter can increase soil permeability by improving soil structure and increasing pore space (Lal, 2004). According to Andyana, el al (2023) the wetter (moister) a soil is, the lower its permeability value. In drier soils, high permeability will result in a reduced ability of the soil to hold water and nutrients.

Based on the data from the analysis of soil damage status, the pH in one SLH is classified as damaged with a percentage of 5.8%. Soil pH indicates the acidity or basicity of the soil, and the ideal pH for most plants is between 6.0 and 7.0 (Havlin et al., 2016). pH that is too low (acidic) or too high (basic) can affect the availability of nutrients for plants. In terms of soil type, laboratory test results show that the permeability value of Entisol soil is the highest compared to Ultisol and Inceptisol soils, this is due to the high sand composition of Entisol soil, which is 50.05%, so that the soil easily passes water and reduces the occurrence of surface flow (Surono at al., 2013). Hardjowigeno (2003) stated that the first factor affecting the formation process of Entisol is a very dry climate, so weathering and chemical reactions run very slowly. Oxisol is a mineral soil that has undergone advanced weathering. This soil is commonly called old soil. The specific feature of Oxisol soils is the presence of oxic horizons whose upper limit is at a depth of 150 cm or less from the surface of the mineral soil and there are no kandic horizons at that depth (Hardjowigeno, 2003; Soil survey staff, 2014). In addition, Oxisol soils are characterized by low natural fertility, low organic matter content, and relatively acid pH (Carducci et al., 2017).

3.3 Distribution of Potential and Status of Soil Damage in Sawan Sub- District:

The distribution of potential soil damage on dry land varies in Sawan Sub-district, Buleleng Regency. The potential for light damage is spread in SLH 2, 3, 4, 5, 7, 8, 10, 13, 14, 15 and 16 with a percentage of 64.7%. Medium damage potential is spread in SLH 1, 9, 11, 12 and 17 with a percentage of 29.4% and potential for light damage in SLH 6 with a percentage of 5.8%. The distribution map of potential soil damage is presented in Figure 2.

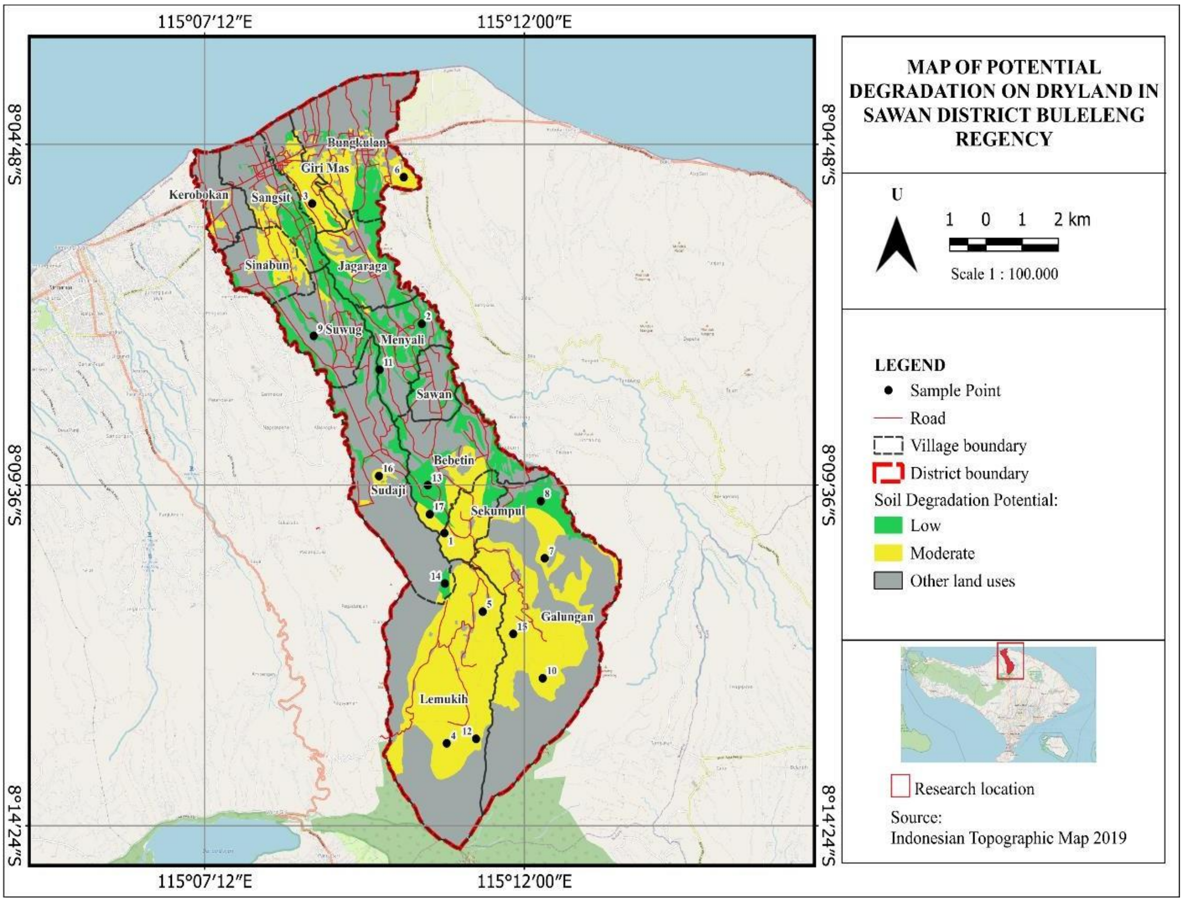

FIGURE 2: Map of Potential Damage to Dry Land in Sawan Sub-District

The actual conditions in the field only show land with mild soil damage status which is divided into three classes based on the limiting factors in it. In SLH 2, 3, 4, 5, 7, 8, 10, 13, 14, 15 and 16 which are located in Bebetin Village, Giri Emas Village, Lemukih Village, Sekumpul Village and Sudaji Village covering an area of 2,278.62 ha with a percentage of 64.7% no factors causing soil damage status were found so that it is classified as good (N). In SLH 1, 9, 11, 12 and 17 located in Sudaji Village, Suwug Village and Lemukih Village covering an area of 814.92 ha with a percentage of 29.4% potential for light damage factor of mild soil damage status on dry land is permeability (R.I.p). In SLH 6 in Bungkulan Village spread over an area of 50.52 ha with a percentage of 5.8% the factors causing the status of heavy soil damage on dry land are content weight, pH, and permeability (R.I.d.p.a). Field conditions that have undergone various changes such as land management by farmers and conservation measures applied are factors that differentiate the results of the analysis between the potential and status of soil damage. A map of the actual distribution of the soil damage status is presented in figure 3.

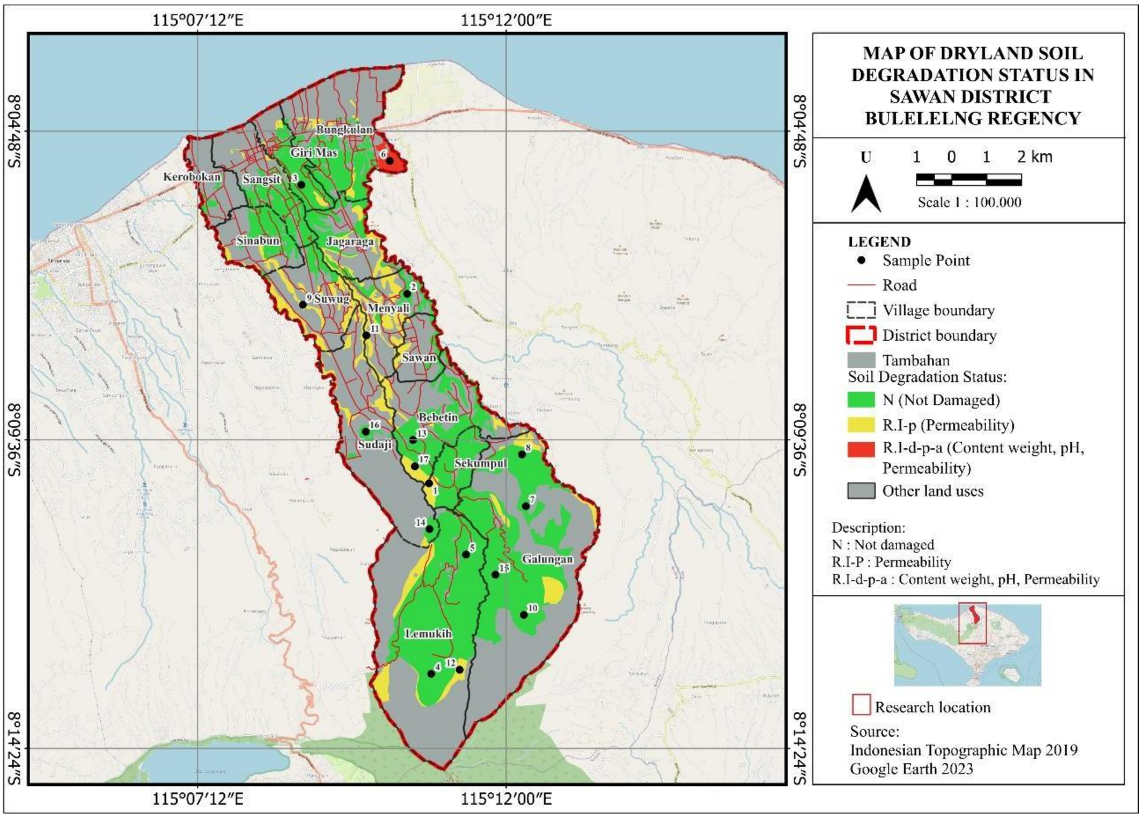

FIGURE 3: Map of Dry Land Soil Damage Status in Sawan Sub-District

3.4 Improvement Efforts:

Soil improvement efforts can be done by adding organic materials and tillage. The application of organic matter in the form of compost or manure into the soil causes an increase in soil C-organic levels (Syukur and Indah, 2006). Barzegar et al. (2002) reported that the application of organic matter in the form of manure plays a role in improving the weight of soil content in the tillage layer (0-20 cm). Organic matter also provides nutrients for microbial activity in decomposition activities, improves soil stability, and increases soil recoverability (Limbong, 2017). Therefore, the addition of organic matter is a comprehensive strategy to improve soil quality and increase agricultural productivity. The positive impact of this improvement is that it can increase soil looseness, improve soil aeration and drainage, and facilitate tillage.

Soil management can affect soil physical properties, including texture, soil permeability, volume weight, total pore space, moisture content, and aggregate stability. In addition, the use of crop residues will be embedded into the soil, increasing soil looseness and further increasing soil permeability. The process of soil loosening is also beneficial in helping to restore the condition of the growing medium to be fertile, making it easier for plant roots to penetrate the soil, reducing the leaching of nutrients that support plant growth. In addition, crop rotation is one way of soil management that must be applied, effective rotation will increase soil microbiological activity and improve soil structure (Sutanto, 2002).

IV. CONCLUSION

Potential soil damage on dry land in Sawan Subdistrict, Buleleng Regency obtained two classes of potential damage, namely lightly damaged (PR.II) and moderately damaged (PR.III) and there are soil damage status, namely not damaged (N), lightly damaged (R.I.p) with limiting factors of permeability and light damage (R.I-d-p-a) with limiting factors of content weight, pH and permeability. The potential distribution of lightly damaged soil damage is scattered in SLH 2, 8, 9, 11, 13 and 14 located in Bebetin Village, Suwug Village and Sekumpul Village spread over 1,330.95 ha with a percentage of 35.3% and the potential for moderate damage is scattered in SLH 1, 3, 4, 5, 6, 7, 10, 12, 15, 16 and 17 located in Sudaji Village, Giri Emas Village, Lemukih Village, Bungkulan Village, Bebetin Village and Sekumpul Village spread over 1,813.11 ha with a percentage of 64.7%. The actual distribution of damage status in the field includes: Undamaged status (N) in SLH 2, 3, 4, 5, 7, 8, 10, 13, 14, 15 and 16 with a distribution percentage of 64.7% light soil damage status (R.I.P) spread in SLH 1, 9, 11, 12 and 17 with a distribution percentage of 29.4% and light soil damage status (R.I.d.p.a) spread in SLH 6 with a distribution percentage of

5.8%. Management directions recommended for improvement are the addition of organic materials and tillage and can be done by rotating crops or crop rotation.

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Emergence of Zero Budget Natural Farming in Himachal Pradesh: Prospects and Challenges

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Abstract— *Zero Budget Natural Farming (ZBNF) is an agricultural method that does not require external inputs. This study, based on secondary data, analyses the number of farmers practicing natural farming and the land area under cultivation, as well as the prospects and challenges of ZBNF in Himachal Pradesh. The study reveals that Kangra district had the highest farmer adoption rate (22.33 per cent) under ZBNF, while Lahaul-Spiti had the lowest (0.46 per cent). Mandi had the largest area under ZBNF (24.61 per cent), and Lahaul-Spiti the smallest (0.71 per cent) from 2018-19 to 2022-23. The percentage growth rate of area under ZBNF was observed to be 156.20 per cent, and for the number of farmers, it was 1069.58 per cent from 2018-19 to 2022-23, indicating overall increases in both farmers' adoption and area expansion for ZBNF practices. A high positive correlation of 0.9681 has been found between the number of farmers and the area under ZBNF. The study underscores the need to target more farmers and expand the cultivation area under ZBNF, as it is crucial for protecting soil fertility, providing healthy and chemical-free food. Therefore, the government and stakeholders should promote ZBNF and offer technical knowledge on best practices.*

Keywords— Natural Farming, ZBNF, Sustainable Agriculture, Pillars of ZBNF, Pest Management in ZBNF.

JEL classifications: Q01, Q10, Q15, Q16, Q24.

I. INTRODUCTION

In India, Himachal Pradesh is the only state where 89.96 per cent of the population residing in rural areas where agriculture and horticulture directly employ approximately 70 per cent of the state's total workforce (GoHP, 2021). In the context of food insecurity, global warming, climate change, natural resource depletion, migration, and farmer suicides, Zero Budget Natural Farming (ZBNF) may be the world's most successful agrarian movement in terms of reach (Biswas, 2020).

Most farmers depend heavily on inorganic chemical inputs like fertilizers and pesticides, which contribute to groundwater pollution and harm water-dependent ecosystem. This practice also causes a gradual decline in soil fertility and poses significant health risks to farmers across India due to the continuous use of chemicals and pesticides. In line with the central government's target to double the farmers' income by 2022, natural farming method promoted by Padma Shri awardee Shri Subhash Palekar, are seen as essential strategies for achieving this objective (Mahajan and Dev, 2022).

Zero Budget Natural Farming is an agricultural approach that involves no initial financial outlay or spending on external inputs. If cost is incurred by chance, it is offset by profitable production. ZBNF is gaining momentum for its ability to enhance soil health over the long term, fostering diversified crops, encouraging microbial activities, and facilitating nutrient recycling, and promoting beneficial biological interactions. Particularly in rain-fed areas where the impact of the green revolution is less important, ZBNF emerges as a promising alternative in the face of unpredictable weather conditions. It represents an extreme form of low external input sustainable agriculture (LEISA), wherein all inputs are locally sourced (on the farm), and the output of one farming system serves as the primary input for another farming system (Biswas, 2020).

The government of Himachal Pradesh introduced the '*Prakritik-Kheti-Khushhal-Kisan-Yojna'* (PK3Y) through adoption of 'Subhash Palekar Natural Farming' to boost ZBNF across various cereal crops such as paddy, wheat and wheat. Efforts have also been made to produce vegetables and fruits in the state (GoHP, 2020, 2023). In the financial year 2023-24, a budget provision of ₹13.00 crore has been made to the *Prakritik-Kheti-Khushhal-Kisan-Yojna* under ZBNF (GoHP, 2024). Several factors, including soil protection techniques, mulching, natural pesticides and fertilizers, less number of inputs, chemical-free produce, organic manures, limited irrigation needs, and cost-effectiveness, plays a crucial role in influencing the adoption of natural farming. In the era of modernization, information dissemination through mass media channels such as the internet, newspapers, and word of mouth from friends and family has become the primary source of information (Gamoh et al., 2022; Kumar and Kumari, 2020).

Under '*Prakartik-Kheti-Khushhal-Kisan-Yojna'*, workshops and trainings are being organized to inform farmers about natural farming. ZBNF promises to drastically cut production costs. It eliminates the need for loans for farming activities by relying entirely on internal inputs. Therefore, the government and concerned stakeholders should prioritize providing effective technical knowledge on best natural farming practices (Kumar and Kumari, 2020; Biswas, 2020; Mahajan and Dev, 2022).

With the deepening of the theoretical exploration of Zero Budget Natural farming in academia, scholars have begun to pay attention to the area and farmers' adoption level of this farming. For example, the study analysed by Choudhary et al (2012) assessed that the development, dissemination, and adoption of low-cost integrated farming system models would greatly encourage hill farmers to diversify their farming to increase productivity and profitability. Choudhary (2013) has suggested, the improved farming technology offers significant potential to boost pulse productivity, profitability, and water use efficiency through a frontline demonstration program in Himachal Pradesh. Choudhary and Suri (2014) showed that the demonstrated farm technology has great potential to increase oilseed productivity, profitability, and water-use efficiency, allowing resource-limited hill farmers in Himachal Pradesh to earn better livings. Yadav et al (2015) found that there is a need to educate and aware farmers about better technology through trainings and demonstrations, as well as ensure the availability of critical inputs on time, in order to close production gaps in maize in Himachal Pradesh.

Further, Bishnoi and Bhati (2017); Kumar et al (2019); Korav et al (2020); Ranjan and Sow (2021) defined the meaning as well as four pillars (Jivamrita, Bijamrita, Acchadana and Whapasa) and principle method of ZBNF which incorporates crop rotation, green manures and compost, biological pest control, and mechanical cultivation. Bharucha et al (2020) found that the statistically significant differences in yield and farmers' income between ZBNF and Non-ZBNF practices across various locations and crops. As per the available literature, natural farming is a new technology or practice that has been adopted by farmers in recent years and known as the '*Prakartik-Kheti-Khushhal-Kisan-Yojna'* in the state. The studies mentioned above pertain to different time periods and employ various methodologies. Most of the studies focus on theoretical aspects, while very few are based on analysing the trends of natural farming in Himachal Pradesh.

The present study focuses and attempt to analyse the trends of area and farmers under ZBNF from 2018-19 to 2022-23 in Himachal Pradesh. The specific objectives are: to analyse the trends and percentage growth rate in area and number of farmers under ZBNF in HP; to identify the correlation between area and number of farmers under ZBNF in HP.

II. DATA SOURCES AND METHODOLOGY

The present study is based on secondary data which is compiled from '*Prakritik-Kheti-Khushhal-Kisan-Yojna'* under ZBNF, Directorate of Agriculture, Government of Himachal Pradesh, Shimla. This scheme was started in 2018 in the state. Data related to the area under natural farming and farmers practicing under natural farming are recorded for the period 2018-19 to 2022-23 only, due to the limitation of time period. The data have been analysed through percentage growth rate, and correlation between area and the numbers of farmers under ZBNF.

The percentage growth rate has been calculated for the years from 2018-19 to 2022-23 for the area and the number of farmers under natural farming. This analysis was carried out for the entire state. To compute percentage growth rate, the following formula has been used.

$$Percentage\ Growth\ Rate = \frac{PV - IV}{IV} \times 100 \quad (1)$$

The given formula represents that, PV is the present value and IV is the initial value.

III. RESULTS AND DISCUSSIONS

3.1 Emergence of Zero Budget Natural Farming in Himachal Pradesh:

This section analyses the percentage of farmers and area practicing under natural farming during the period 2018-19 to 2022-23. After that, the performance of natural farming in Himachal Pradesh has been analysed through percentage growth rate and correlation between the number of farmers and area under natural farming.

Table 1 depicts that the farmers and area under natural farming have been recorded about 1.77 per cent and 7.43 per cent, respectively, in the adoption year 2018-19. This indicates that a small number of farmers are working over a relatively small area. Similarly, there is a significant increase in both the number of farmers (25.02 per cent) and the area (25.48 per cent) during 2019-20.

Likewise, the number of farmers increased slightly by 27.36 per cent, while the area increased by 26.87 per cent during 2020-21. This could indicate a substantial expansion in farming activities or more farmers participating in agriculture. This indicates a major change, potentially due to factors like the expansion of land under cultivation.

TABLE 1
AREA AND FARMERS UNDER ZBNF: 2018-19 TO 2022-23

(in %)

Years	Farmers	Area
2018-19	1.77	7.43
2019-20	25.02	25.48
2020-21	27.36	26.87
2021-22	25.21	21.19
2022-23	20.65	19.04

Source: Computed from ZBNF data, Department of Agriculture, Government of Himachal Pradesh, Shimla.

Furthermore, there is a decline in both the number of farmers (25.21 per cent) and the area (21.19 per cent) during 2021-22. This could indicate a contraction in farming activities, possibly due to adverse conditions such as poor weather, economic challenges, or shifts in policy. Moreover, the number of farmers and area decreased to 20.65 per cent and 19.04 per cent during 2022-23.

The lower numbers of farmers and area could reflect the initial phase where limited awareness and resources, participation, and area coverage were still growing. During the COVID-19 pandemic peak period 2020-21, the agricultural sector saw a significant increase in both the number of farmers and the area under cultivation. This was largely due to economic disruptions that caused many urban workers to return to rural areas and engage in farming as a means of livelihood and food security, as it ensured low costs, health benefits and long-term sustainability. The reverse migration to rural areas further contributed to the temporary surge in agricultural activity.

Table 2 depicts that the Kangra and Mandi districts have the highest percentages of both farmers and agricultural area with 22.33 per cent of the farmers and 20.66 per cent of the area in Kangra, indicating this district is a significant agricultural hub, and in Mandi district 21.61 per cent of the farmers and 24.61 per cent of the area, similar to Kangra, representing a substantial role in the region's agriculture.

TABLE 2
DISTRICT WISE FARMERS AND AREA UNDER ZBNF: 2018-19 TO 2022-2023

(in %)

Name of District	Farmers	Area
Bilaspur	3.11	3.31
Chamba	8.55	5.82
Hamirpur	8.56	8.69
Kangra	22.33	20.66
Kinnaur	1.41	2.09
Kullu	6.86	5.17
L & S	0.46	0.71
Mandi	21.61	24.61
Shimla	9.47	9.16
Sirmaur	5.24	5.65
Solan	5.63	6.70
Una	6.79	7.43

Source: Computed from ZBNF data, Department of Agriculture, Government of Himachal Pradesh, Shimla.

Similarly, Lahaul & Spiti (L & S) and Kinnaur have the lowest percentages, with 0.46 per cent of the farmers and 0.71 per cent of the area in Lahaul & Spiti, and 1.41 per cent of the farmers and 2.09 per cent of the area in Kinnaur, due to harsh climate, high-altitude terrain, limited arable land, and scarce water resources, which make large-scale farming practices challenging. This indicates that these are the least agriculturally intensive districts relative to others. Additionally, the remoteness and lower population density of Lahaul & Spiti further limit the adoption and expansion of natural farming in the district. Moreover, the high area under natural farming in Mandi and Kangra districts can be attributed to their favorable climate, fertile soil, larger farming population, and better accessibility and infrastructure, which support extensive agricultural activities.

3.2 Pillars of Zero Budget Natural Farming:

The four pillars of ZBNF are essential for promoting sustainable agriculture, reducing farmers' dependence on costly external inputs, creating a self-sustaining, cost-effective, and eco-friendly farming system. These four pillars are;

3.2.1 Jivamrita/Jeevamrutha:

Jeevamrutha also known as jivamrita, is a natural bio-fertilizer composed of 200 liters of water, 10 kg of desi cow dung, 5 to 10 liters of desi cow urine, 2 kg of jaggery, 2 kg of pulse flour, and a handful of soil. It enhances soil microbial activity, improving nutrient availability for crops and boosting soil fertility. This promotes healthy plant growth and reduces the dependence on chemical fertilizers, fostering sustainable farming practices (Ranjan and Sow, 2021; Kuamr, 2021; Korav et al., 2020; Kumar and Kumari, 2020; GoHP, 2023).

3.2.2 Bijamrita/Beejamrutha:

Beejamrutha is also called Bijamrita, specifically used for seed treatment and focuses on protecting seeds from diseases. The ingredients typically include desi cow urine, cow dung, lime, water, and a small amount of soil. Its primary function is to coat the seeds with beneficial microbes, protecting them from soil-borne diseases and promoting healthy germination (Kumar, 2021; Ranjan and Sow, 2021; Korav et al., 2020; Kumar and Kumari, 2020; GoHP, 2023).

3.2.3 Acchadana/Mulching:

Covering the soil with dust or plant materials (Acchadana/Mulching) offers several benefits. As Palekar suggests there are three types of mulching they are a) soil mulching b) straw mulching (Kumar and Kumari, 2020) c) live mulching. Soil mulching involves protecting the topsoil during cultivation to improve aeration and water retention, while straw mulching uses decomposing organic material from plants or animals to cover the soil. According to Palekar, live mulching is important and involves growing diverse cropping patterns of monocotyledons and dicotyledons to enhance soil health (Kumar, 2021; Ranjan and Sow, 2021; Korav et al., 2020; GoHP, 2023).

3.2.4 Whapasa/Moisture:

According to Palekar, roots mostly demand water vapour. Whapasa is distinguished by the presence of both water and air molecules (Kumar, 2021). ZBNF includes practices for water conservation and efficient water use based on the specific needs of crops. Whapasa improves water efficiency by reducing irrigation frequency and applying water in small amounts at noon in alternate furrows, which helps retain both air and moisture in the soil (Ranjan and Sow, 2021; Kumar and Kumari, 2020; GoHP, 2023).

3.3 Pest Management in Zero Budget Natural Farming:

Crops can suffer significant damage from pests and diseases, with weeds producing the greatest yield loss, followed by pests and diseases. Addressing these problems is a key challenge in natural farming. Plant extracts are used to develop effective treatments for insect control, with protection methods including blends of buttermilk, cow milk, pepper powder, neem seeds, and green chilies (Korav et al., 2020). Some research papers have identified and described various naturally extracted, chemical-free compounds. They are:

3.3.1 Agniastra:

The mixture contains 20 litres of desi cow urine, 500 grammes of tobacco, 500 grammes of green chilli, 500 grammes of local garlic, and 5 kilogrammes of neem leaves pulp mashed in cow urine. It should be kept cool place after preparation. To spray one acre, combine 6-8 litres of Agniastra (left over from boiling) with 200 litres of water. This treatment is particularly successful in controlling pests such as leaf roller, stem borer, pod borer, and fruit borer (Korav et al., 2020; Kumar and Kumari, 2020).

3.3.2 Brahmastra:

An alternative method to manage pest populations in natural farming involves the gathering of various plant leaves, such as neem, castor (eranda), custard apple leaves, lantern camellia, pomegranate, guava, papaya, and white datura leaves. These leaves are crushed and boiled in desi cow urine, and the resulting mixture is then filtered. Once filtered, the extract can be stored for extended periods of time. This method proves highly efficient against various pests, including sucking pests, pod borers, fruit borers, and others. For 1acre 2.5-3 litres solution mix in 200 litres water and used as spray (Korav et al., 2020; Kumar and Kumari, 2020).

3.3.3 Neemastra:

Comprising 5 liters of local cow urine, 5 kilograms of cow dung, 5 kilograms of neem leaves, and 100 liters of water, this solution is created by mixing all the ingredients. It is ready for use after 48-72 hours and is applied on 1 acre of land. Its primary efficacy lies in controlling sucking pests and Mealy Bugs (Kumar and Kumari, 2020; Korav et al., 2020).

3.3.4 Dashparni ark:

Consisting of 200 liters of water, 20 liters of local cow urine, 2 kg of cow dung, 500 grams of turmeric powder, 500 grams of ginger paste, 200 grams of asafoetida (heeng) powder, 1 kg of tobacco powder, 1 kg of green chilli paste, 1 kg of garlic paste, and 2-2 kg leaves from 10 different plants including castor (eranda), custard apple, neem karang, bael, datura, aak, mango, guava, marigold, and turmeric. Subsequently, these materials are mixed, and the solution is ready for application on 1 acre of land after 28 days (Kumar and Kumari, 2020).

Table 3 represents that the number of farmers are extremely high positive growth rate (1316.71 per cent) from 2018-19 to 2019-20, indicates a very substantial increase in the number of farmers participating in ZBNF. Similarly, the area under ZBNF also saw a significant increase (242.91 per cent) during the same period. This represents that not only more farmers are adopting ZBNF, but they are also applying it over much larger areas. This could be due to several reasons, such as a new policy initiative, government incentives, increased awareness, or a shift in agricultural practices toward sustainable farming.

Likewise, the growth rate for farmers slowed down significantly to 9.34 per cent during 2019-20 to 2020-21, indicating a much smaller increase in the number of farmers participating in ZBNF. Although still positive, the area under ZBNF also saw a reduced growth rate compared to the previous year, but it remained substantial at 5.48 per cent. This represents a continued expansion in ZBNF coverage, albeit at a slower pace. This could mean that after the initial surge in participation, growth stabilized, or that most of the farmers who were likely to switch to ZBNF had already done so

TABLE 3
PERCENTAGE GROWTH RATE OF FARMERS AND AREA UNDER ZBNF: 2018-19 TO 2022-23

Years	Farmers	Area
2018-19 to 2019-20	1316.71	242.91
2019-20 to 2020-21	9.34	5.48
2020-21 to 2021-22	-7.85	-21.17
2021-22 to 2022-23	-18.07	-10.15
2018-19 to 2022-23	1069.58	156.20

Source: Computed from ZBNF data, Department of Agriculture, Government of Himachal Pradesh, Shimla.

Similarly, the growth rate became negative, indicating a decline in the number of farmers participating in ZBNF by 7.85 per cent, whereas the area under ZBNF saw a sharp decline of 21.17 per cent. Moreover, the number of farmers and area under ZBNF continued to decline with 18.07 per cent and 10.15 per cent during the period 2021-22 to 2022-23. Likewise, the growth rate for farmers observed to be 1069.58 per cent, and for area, it was 156.20 per cent, which shows a substantial increment in growth rates from 2018-19 to 2022-23.

The correlation value given in Table 4 indicates a high and positive relationship between the two variables. A value of 0.9681 represents that as the number of farmers increases, the area under consideration also tends to increase, and vice versa.

TABLE 4
CORRELATION MATRIX OF FARMERS AND AREA UNDER ZBNF: 2018-19 TO 2022-23

	Area	Farmers
Area	1.0000	0.9681
Farmers	0.9681	1.0000

3.4 Prospects of Zero Budget Natural Farming:

The cost of production under ZBNF is considered zero because farmers do not need to purchase inputs from the market. It aims to eliminate dependence on credit and costly external inputs, enabling farmers to avoid debt and practice sustainable, low risk farming, thereby reducing the engagement of hired manual labour. It also requires less effort and time (Das et al., 2022). It uses only 10 per cent of the water that typical crop cultivation methods do. In one month, one cow may produce 10-12 kg of fresh dung, which is sufficient for 30 acres of land. Significantly, higher yields were discovered under ZBNF in many cash and food crops, such as fruits, vegetables and spices. ZBNF farms are resilient to prolonged droughts and flooding. Growing various crops and border plants on the same plot helps improve soil fertility and nutrient levels (Das et al., 2022; Ranjan and Sow, 2021; Korav et al., 2020). Overall, ZBNF practices lead to reduced water and electricity usage, better farmer health, and the preservation of local ecosystems and biodiversity. This also eliminates toxic residues in the environment and enhances soil quality, biodiversity, livelihoods, water management, better environmental health, reduced greenhouse gas emissions, increased farmer income, climate resilience, women's empowerment, and nutrition (Korav et al., 2020; Biswas and Pakhira, 2023).

Among the various natural farming methods used worldwide, ZBNF has gained significant popularity in India. Andhra Pradesh, Himachal Pradesh, and Gujarat are the leading states promoting this model, with others like Uttar Pradesh, Madhya Pradesh, Odisha, Chhattisgarh, and Uttrakhand also adopting it. India's diverse agro-climatic conditions and the rich traditional knowledge of its farmers present numerous opportunities to expand natural farming practices (Biswas and Pakhira, 2023).

The Green Revolution, with its focus on high-yielding varieties, chemical fertilizers, and pesticides, has led to reduced soil health by depleting essential nutrients, harming beneficial microbes, accumulating toxins, and contaminating groundwater. These practices also contribute to environmental and health issues, with burning crop residues further decreasing soil organic matter and increasing air pollution. As globalization heightens the need for environmental sustainability, natural farming offers a viable solution to these problems (Korav et al., 2020). Overall, natural farming is a vital strategy for protecting the planet and ensuring the well-being of future generations (Biswas and Pakhira, 2023).

IV. CHALLENGES OF ZERO BUDGET NATURAL FARMING

ZBNF is nature-friendly and sustainable, as it boosts beneficial microbes, provides chemical-free nutrients, and ensures toxin-free food for humans and animals. However, its broader adoption faces several hurdles; it demands more labor and animal manure, which is unsustainable with India's current cattle population. It also requires significant investment and advanced technology but avoids heavy machinery to prevent soil compaction. Additionally, natural products often have limited market value and are priced similarly to chemically produced goods due to underdeveloped agricultural market infrastructure. Natural farming can produce yields comparable to or greater than chemical farming, but profitability may be low due to limited market access and a lack of premium prices. With the growing global population and food scarcity concerns, meeting production goals without chemical inputs or hybrid crops remains a challenge.

Managing crop-specific weeds, diseases, and pests using natural methods can be ineffective for farmers. The limited availability of indigenous cows, crucial for manure in ZBNF, further complicates its practice. Despite being introduced by Mr. Subhash Palekar, ZBNF has not widely accepted in his home state of Maharashtra. Additionally, there is a need for specialized practices suited to various crops, which requires development of guidelines by state colleges, government institutions, and extension workers (Korav et al., 2020).

V. CONCLUSION AND POLICY IMPLICATION

Zero Budget Natural Farming is an agricultural method that requires no initial investment and eliminates the need for purchased inputs. It enhances sustainability by reducing water and electricity usage, protecting farmer health, preserving local ecosystems, and preventing toxic residues. There is a positive and high correlation (0.9681) between the area under cultivation and the number of farmers. This represents the number of farmers, and the area under consideration also tends to increase.

In the face of challenges such as food insecurity, climate change, resource depletion, migration, and farmer suicides, ZBNF has emerged as a highly effective global agricultural movement. So that the government and other stakeholders should prioritize the promotion of the ZBNF in the state.

To promote ZBNF, it is essential to allocate a larger share of the union budget (10-15 per cent) should go towards agriculture. To realize the potential of natural farming, farmers, government organizations, academic institutions, and consumers must work together. Investments in infrastructural developments, capacity building, and research and development may help natural farming practices spread across the nation.

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Effect of Transplanting Plant Numbers per Hill on Heterosis in Hybrid Rice

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Abstract— *Hybrid rice is the primary cereal crop in Southern China, playing a crucial role in national food security. With a yield advantage of 15–20% over inbred varieties, agronomic practices. Planting density including inter-plant spacing and the number of transplanted plants per hill has a fundamental effect on rice production. However, the impact of transplanting plant numbers per hill on the expression of hybrid vigor remains unclear. This study evaluates the effects of different transplanting densities under sparse planting conditions on key physiological and yield-related traits in hybrid rice, its paternal lines, and inbred varieties. Results indicate that transplanting plant numbers per hill significantly influence heterosis, affecting key traits such as better-parent heterosis (BPH), plant height (PH), spikelets per panicle (SPP), seed setting rate (SSR), harvest index (HI), and overall yield. The optimal transplanting density for maximizing yield was 1–2 plants per hill for hybrid rice and 3–4 plants per hill for inbred varieties. These findings provide a theoretical foundation for breeding, high-yield cultivation, and the mechanized adoption of hybrid rice.*

Keywords— hybrid rice; heterosis; yield traits; transplanting density; restorer lines.

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I. INTRODUCTION

Rice (*Oryza sativa* L.) is a staple food crop, with China contributing over one-fourth of global rice production. It provides essential energy and nutrition to approximately 65% of the Chinese population[1]. Hybrid rice has played a critical role in ensuring food security, yielding 15–20% more than inbred cultivars[2]. The best cultivation measures, including transplanting density, number of transplanted plants, and fertilization measures, can achieve the highest yield of hybrid rice.This yield advantage is primarily attributed to increased grain weight, biomass accumulation, and extended growth duration, which enables better utilization of environmental resources such as temperature, light, and heat[3-6]. With the widespread adoption of hybrid rice, optimizing cultivation practices is essential to fully exploit its yield potential. Among agronomic factors, planting density—including inter-plant spacing and the number of transplanted plants per hill—is a fundamental determinant of rice productivity[7]. Recent advancements in agricultural mechanization, alongside labor shortages, have made machine transplanting the preferred method due to its efficiency and control over spacing and transplanting density [8]. The number of seedlings per hill at transplanting is particularly influential, directly affecting rice growth and yield formation [9]. Thus, systematic evaluation of transplanting density is necessary to refine high-yield cultivation strategies for hybrid rice and inbred varieties.

Hybrid rice yield is strongly influenced by planting density, which modulates critical yield traits such as effective panicles per hill (EPN), spikelets per panicle (SPP), seed setting rate (SSR), and 1000-grain weight (KGW). Proper density management balances inter-plant competition and compensation, enhancing yield. Historically, inbred rice yield in China was increased in the 1960s through high-density planting to maximize panicle number per unit area. In contrast, the 1980s saw the adoption of sparse planting for large-panicle hybrid rice, which optimized plant architecture by reducing excessive tillering and increasing panicle size rather than panicle number [10, 11]. The number of seedlings per hill is a key factor in yield optimization. Under constant planting density, an increase in seedlings per hill initially enhances effective panicle formation but eventually reduces yield due to a decline in spikelets per panicle and increased competition[12]. Excessive seedling numbers per hill promote ineffective tillering, reducing panicle productivity and limiting yield gains [13]. Conversely, an appropriate seedling number per hill, coupled with optimal spacing, can improve population structure, minimize ineffective tillers, enhance tiller-to-panicle conversion rates, and optimize yield component relationships [14].

The yield potential of super high-yielding hybrid rice in China has risen from 10.5 t/ha to 15 t/ha [15]. Given the importance of transplanting practices, it is hypothesized that the number of plants per hill significantly affects the expression of heterosis in hybrid rice. Since farmers commonly adopt sparse planting densities, it is crucial to evaluate the impact of transplanting plant numbers per hill under these conditions. This study systematically compares key physiological and yield traits in different hybrid rice genotypes, their parental lines, and inbred varieties, clarifying the role of transplanting density in the expression of heterosis. The findings provide a theoretical basis for breeding, high-yield cultivation, and the mechanization of hybrid rice production, contributing to food security.

TABLE 1
MAIN RICE VARIETIES USED IN THE EXPERIMENT

Variety	Male steril line	Restore line	Super rice	Certification	Breeding unit
LYP9	P64s	R9311	1st	National approved 2001001	Hunan Hybrid Rice Research Center
YLY1	Y58s	R9311	2nd	National approved 2008001	Hunan Hybrid Rice Research Center
YLY2	Y58s	YH2	3rd	National approved 2013027	Hunan Hybrid Rice Research Center
YLY900	Y58s	R900	4th	National approved 2015034	Hunan Hybrid Rice Research Center
HHZ				National approved 2007018	Rice Research Institute, Guangdong
XWX17				National approved 2008035	Hunan Rice Research Institute

TABLE 2
MAIN SOIL PROPERTIES OF EXPERIMENTAL PADDY FIELD

Soil sample	Total N(g/kg)	Total N(g/kg)	Total N(g/kg)	pH	Organic matter (%)
1	1.75	0.93	9.93	5.7	2.92
2	1.53	0.79	8.14	6.0	2.89
3	1.17	0.63	10.69	5.8	1.99
4	1.91	0.78	10.13	6.5	3.75
5	1.91	0.73	10.98	6.4	3.94
6	1.74	0.91	10.39	6.4	3.52
Mean	1.67	0.80	10.04	6.13	3.17

TABLE 3
MAIN RICE VARIETIES ARRANGEMENTS AND GROWTH PERIOD IN THE EXPERIMENT

Year	Variety	Sowing date	Transplanting date	Heading date	Milk ripening date	Mature date	Whole growth period
2016	LYP9	2016/5/28	2016/6/22	2016/9/13	2016/9/15	2016/10/4	129
2016	YLY1	2016/5/28	2016/6/22	2016/9/13	2016/9/15	2016/10/4	129
2016	R9311	2016/5/28	2016/6/22	2016/9/13	2016/9/15	2016/10/4	129
2016	YLY2	2016/5/28	2016/6/22	2016/9/13	2016/9/15	2016/10/4	129
2016	YH2	2016/5/28	2016/6/22	2016/10/4	2016/10/5	2016/10/28	153
2016	YLY900	2016/5/28	2016/6/22	2016/9/13	2016/9/15	2016/10/4	129
2016	R900	2016/5/28	2016/6/22	2016/10/4	2016/10/5	2016/10/28	153
2016	HHZ	2016/5/28	2016/6/22	2016/8/29	2016/9/1	2016/9/25	120
2016	XWX17	2016/5/28	2016/6/22	2016/8/29	2016/9/1	2016/9/25	120

II. MATERIALS AND METHODS

2.1 Experimental sites and materials:

Field experiments were conducted at the Hunan Hybrid Rice Research Center experimental base (28°12′N, 112°59′E, altitude 73 m) in Changsha County, Hunan Province, China, during the 2015–2016 growing seasons under a subtropical climate. The primary experimental materials included super high-yielding hybrid rice varieties (LYP9, YLY1, YLY2, YLY900), restorer lines (R9311, YH2, R900), and inbred control varieties (HHZ and XWX17) (**Table A1 and 1**), all of which are widely cultivated in China. The experimental field had a high nitrogen content, with key soil properties summarized in **Table 2**. In 2015, the field was fertilized with 50 kg/ha of potassium fertilizer (KCl ≥40%, K_2O ≥22%) sourced from Canada and 200 kg/ha of compound fertilizer (N-P-K: 16%-16%-16%). In 2016, 375 kg/ha of compound fertilizer (N-P-K: 16%-16%-16%) was applied after transplanting. Field irrigation and management followed standard local farming practices.

2.2 Experimental design and sampling measurements:

The transplanting plot size was 19.8 cm × 26.4 cm. In 2015, each variety was transplanted with 1, 1, 2, or 4 plants per hill (PPH1-4), while in 2016, 1, 2, 3, or 4 plants per hill (PPH1-4) were used. Each plot covered an area of at least 30 m². A randomized complete block (RCB) design was implemented, with each variety treated as a separate factor and replicated three times. Details on sowing and transplanting dates, seedling numbers per hill, and maturity stages for each variety are provided in **Table 3**. Biomass accumulation was measured at different growth stages. Above-ground biomass was determined as the sum of the dry weight of leaves, stems, rachis, and filled, half-filled, and empty spikelets. Six hills per variety were sampled, and plant material was oven-dried at 70 °C for 48 hours until a constant weight was reached. The harvest index (HI) was calculated as the ratio of filled grain weight to total above-ground biomass [16]. Grain yield was assessed from more than 300 hills per plot, manually harvested, and adjusted to a standard moisture content. At maturity, 20 hills per variety were sampled for EPN and PH. Six hills per variety were examined for SPP, SSR, KGW, and HI. Panicles from each hill were hand-threshed, and filled grains were separated from unfilled grains by winnowing. SPP was calculated as the total number of grains divided by EPN, SSR as 100 × (total filled grains / total grains per hill), and KGW as 1000 × (total filled grain weight/number of filled grains per hill).

Heterosis was analyzed using high-parent heterosis (HPH) and standard heterosis (HCK), calculated as follows: $HPH = (F1-HP) / HP \times 100$, $HCK = (F1-CK) / CK \times 100$ where F1 represents the hybrid rice yield traits, HP denotes the best-performing parental restorer line, and CK represents the inbred control variety. All data, including biomass accumulation per hill (BPH), PH, EPN, SPP, SSR, KGW, HI, and yield, were subjected to analysis of variance (ANOVA) using SPSS 17.0. Mean comparisons among varieties were performed using the least significant difference (LSD) test at $P \leq 0.01$ or $P \leq 0.05$. Tables and figures were prepared using Microsoft Excel.

TABLE 4
DRY MATTER ACCUMULATION OF DIFFERENT RICE VARIETIES UNDER DIFFERENT TRANPLANTING PLANT NUMBERS PER HILL AT DIFFERENT STAGE IN 2016

2016-Variety	Tillering stage (Mean±SE)				Heading stage (Mean±SE)				Mature stage (Mean±SE)			
	PPH1	PPH2	3PPH3	PPH4	PPH1	PPH2	PPH3	PPH4	PPH1	PPH2	PPH3	PPH4
LYP9	34.39±5.43 Ab	26.3±2.26 ABCbc	27.08±7.47 Aa	32.07±8.54 ABabc	54.49±7.91 Aab	71.62±6.43 a	67.77±7.07 Aab	83.12±4.70 Ab	115.61±12.97 ABb	108.28±10.57 ABa	148.98±11.25 Bc	102.51±12.18 ABCabc
YLY1	33.06±5.63 Ab	33.55±4.37 BCc	31.98±7.52 ABa	39.79±6.55 ABCcd	78.34±6.88 Ac	70.2±8.69 a	71.02±7.62 Aab	79.85±3.65 Aab	126.93±8.26 Bb	106.66±6.76 ABa	90.98±7.81 Aa	130.5±15.36 BCcd
R9311	27.81±2.22 Aab	29.74±3.17 BCbc	30.97±3.82 ABa	28.25±8.12 Aa	48.96±8.03 Aa	60.09±3.92 a	70.8±12.89Aab	76.02±7.07Aab	97.48±8.33 ABab	95.55±11.58 Aa	92.22±7.67 Aa	139.24±14.12Cd
YLY2	30.91±3.43 Aab	26.55±4.06 ABCbc	36.93±7.85 ABb	39.04±9.37 ABCcd	76.45±4.72 Abc	73.3±8.08 a	76.76±5.16 Ab	68.01±11.51Aab	111.35±6.13 ABab	140.21±16.23 Bb	107.79±9.44 ABab	110.23±16.71 ABCabcd
YH2	19.85±2.95 Aa	14.85±2.95 Aa	41.27±7.84 Bb	40.77±7.59 BCcd	79.55±10.15Ac	67.13±10.67 a	51.62±7.90 Aa	72.57±6.00 Aab	112.51±14.74 ABab	86.22±10.41 Aa	111.33±19.79 ABab	95.16±12.93 ABCabc
YLY900	33.57±5.89Ab	35.73±2.7 Cc	36.04±5.96 ABb	37.89±7.27 ABCbc	59.9±10.05 Aabc	61.64±8.09 a	85.37±6.25 Ab	75.39±5.24 Aab	120.82±15.19 ABb	108.9±10.1 ABab	126.51±10.10 ABbc	125.22±7.92 BCbcd
R900	25.59±2.16 Aab	25.54±5.14 ABCbc	36.18±5.38 ABb	41.27±8.66 Cd	60.11±7.54 Aabc	63.92±6.21 a	64.45±5.5 Aab	67.5±6.88 Aab	104.37±9.16 ABab	106.33±16.63 ABa	104.71±10.42 Aab	86.02±5.56 ABa
HHZ	30.11±5 Aab	34.57±4.93 BCc	42.39±12.44 Bb	44.9±6.04 Cd	77.65±11.95 Abc	76.38±13.39 a	74.03±12.6 Aab	69.14±7.47Aab	100.05±10.18 ABab	88.59±5.16 Aa	97.36±9.86 Aab	74.74±12.98 Aa
XWX17	25.68±2.82 Aab	21.74±1.83 ABa	33.21±5.24 ABa	29.58±7.91 ABab	66.23±4.40 Aabc	66±4.28 a	81.11±3.65 Ab	62.55±4.37 Aa	84.4±9.56 Aa	90.3±4.61 Aa	88.89±11.59 Aa	91.97±10.98 ABCab

The mean of each main yield trait was compared among the different rice varieties (with 1,2,3,4 plants per hill). Within each column, trait differences among varieties are denoted by small letters (not significantly different; p≤0.05) or capital letters (not significantly different; p≤0.01) according to the least significant difference test (LSD). PPH1,2,3,4- 1,2.3,4 plants per hill

III. RESULTS

3.1 Significant heterosis in BPH and PH of hybrid rice:

Biomass accumulation per hill (BPH) is a key determinant of rice yield, varying among different rice varieties and increasing as growth progresses (**Table A2, Table 4**). The heterosis of BPH in hybrid rice was influenced by the number of plants per hill. At the tillering stage in 2015, under transplanting densities of 1, 1, 2, and 4 plants per hill, the high-parent heterosis (HBP%) for BPH ranged from -4.83% to 20.83%. Compared to the inbred control HHZ, the standard heterosis (HCK1%) ranged from -2.41% to 31.17%, while for XWX17 (HCK2%), it ranged from -13.77% to 10.9%. By the heading stage, the HBP% increased to 2.22%–15.27%, with HCK1% ranging from -8.09% to 14.87% and HCK2% from -1.58% to 36.51%. At maturity, HBP% declined to -13.75% to -1.88%, while HCK1% and HCK2% increased significantly, reaching 6.06%–52.2% and 28.15%–64.26%, respectively (**Table A3, Figure A1**).

A similar pattern was observed in 2016, where the effect of transplanting density on BPH heterosis remained evident. At the tillering stage, with 1, 2, 3, and 4 plants per hill, HBP% ranged from -1.44% to 18.96%. HCK1% (HHZ) remained negative (-19.05% to -1.85%), whereas HCK2% (XWX17) ranged from 3.33% to 31.42%. By the heading stage, the trends were consistent with those observed in 2015, with HBP% remaining within -1.44% to 18.96%, HCK1% at -19.05% to -1.85%, and HCK2% at 3.33% to 31.42%. At maturity, hybrid rice exhibited stronger heterosis, with HBP% increasing to 7.19%–22.5%, HCK1% (HHZ) to 18.62%–56.7%, and HCK2% (XWX17) to 27.34%–40.61% (**Table 5, Figure 1**). The BPH heterosis for hybrid rice are the foundation of yield. After heading, the starch stored in the stem is hydrolyzed and transferred to the grain.

For PH, heterosis was similarly influenced by transplanting density. In 2015, under 1, 1, 2, and 4 plants per hill, HBP% ranged from 2.55% to 6.34%, HCK1% (HHZ) from 13.18% to 16.03%, and HCK2% (XWX17) from 7.11% to 14.73% (**Table A4, Figure A2**). In 2016, under 1, 2, 3, and 4 plants per hill, HBP% increased to 5.04%–13.14%, while HCK1% (HHZ) ranged from 10.41% to 12.86%, and HCK2% (XWX17) from 0.64% to 10.21%. These results confirm that PH heterosis in hybrid rice remained positive (**Tables 6, 7, Figure 2**).

Overall, hybrid rice demonstrated lower BPH heterosis at the tillering stage but greater heterosis in mature growth stages. Hybrid and restorer lines consistently exhibited higher BPH than inbred varieties. The number of plants per hill had minimal impact on BPH at maturity, reinforcing that BPH heterosis in hybrid rice was significantly greater than that of restorer and inbred varieties. Similarly, transplanting density had little effect on PH across different varieties, although an increasing trend in PH was observed with higher transplanting densities. Notably, PH heterosis for HBP and HCK declined as transplanting density increased, suggesting that the number of plants per hill plays a role in shaping PH heterosis in hybrid rice. The BPH and PH become an important indicator of the strength of heterosis in hybrid rice. A small number of transplanted seedlings can also achieve the BPH and yield advantage of hybrid rice.

TABLE 5
HETEROSIS FOR DRY MATTER ACCUMULATION OF HYBRID RICE WITH DIFFERENT TRANSPLANTING PLANT NUMBERS PER HILL AT DIFFERENT STAGE IN 2016

Variety-transplanting number-date	Hybird rice （g/hill）			Restore line（g/hill）			HHZ（g/hill）			XW17 (BPH g/hill）			HBP（%）			HCK1 (%)			HCK2 (%)	
	Tillering stage	Heading stage	Mature stage	Tillering stage	Heading stage	Mature stage	Tillering stage	Heading stage	Mature stage	Tillering stage	Heading stage	Mature stage	Tillering stage	Heading stage	Mature stage	Tillering stage	Heading stage	Mature stage	Tillering stage	Heading stage
LYP9-PPH1-2016/8/18	34.39	54.59	115.61	27.81	48.96	97.48	30.11	77.65	100	25.68	66.23	84.4	23.66	11.50	18.60	14.21	-29.70	15.55	33.92	-17.58
YLY1-PPH1-2016/8/18	33.06	78.34	126.93	27.81	48.96	97.48	30.11	77.65	100	25.68	66.23	84.4	18.88	60.01	30.21	9.80	0.89	26.87	28.74	18.28
YLY2-PPH1-2016/8/18	30.91	76.45	111.35	19.85	79.55	112.51	30.11	77.65	100	25.68	66.23	84.4	55.72	-3.90	-1.03	2.66	-1.55	11.29	20.37	15.43
YLY900-PPH1-2016/8/18	19.85	59.9	120.82	25.59	60.11	104.37	30.11	77.65	100	25.68	66.23	84.4	-22.43	-0.35	15.76	-34.08	-22.86	20.76	-22.70	-9.56
Mean	29.55	67.32	118.68	25.27	59.40	102.96	30.11	77.65	100	25.68	66.23	84.4	18.96±16.04	16.82±14.77	15.89±6.45	-1.85±16.04	-13.3±7.64a	18.62±3.36a	15.08±12.9	1.65±8.95a
LYP9-PPH2-2016/8/18	26.3	71.62	108.28	29.74	60.09	95.55	34.57	76.38	88.59	21.74	66	90.3	-11.57	19.19	13.32	-23.92	-6.23	22.23	20.98	8.52
YLY1-PPH2-2016/8/18	33.55	70.2	106.66	29.74	60.09	95.55	34.57	76.38	88.59	21.74	66	90.3	12.81	16.82	11.63	-2.95	-8.09	20.40	54.32	6.36
YLY2-PPH2-2016/8/18	26.55	73.3	140.21	27.88	67.13	86.22	34.57	76.38	88.59	21.74	66	90.3	-4.77	9.19	62.62	-23.20	-4.03	58.27	22.13	11.06
YLY900-PPH2-2016/8/18	27.88	61.64	108.9	25.54	63.92	106.33	34.57	76.38	88.59	21.74	66	90.3	9.16	-3.57	2.42	-19.35	-19.30	22.93	28.24	-6.61
Mean	28.57	69.19	116.01	28.23	62.81	95.91	34.57	76.38	88.59	21.74	66.00	90.30	1.41±5.75	10.41±5.12	22.5±13.59	-17.36±5.75	-9.41±3.4a	30.95±9.12ab	31.42±7.8	4.83±3.93ab
LYP9-PPH3-2016/8/18	27.08	67.77	148.98	30.97	70.8	92.22	42.39	74.03	97.36	33.21	81.11	88.89	-12.56	-4.28	61.55	-36.12	-8.46	53.02	-18.46	-16.45
YLY1-PPH3-2016/8/18	31.98	71.02	90.98	30.97	70.8	92.22	42.39	74.03	97.36	33.21	81.11	88.89	3.26	0.31	-1.34	-24.56	-4.07	-6.55	-3.70	-12.44
YLY2-PPH3-2016/8/18	36.93	76.76	107.79	41.27	51.62	111.33	42.39	74.03	97.36	33.21	81.11	88.89	-10.52	48.70	-3.18	-12.88	3.69	10.71	11.20	-5.36
YLY900-PPH3-2016/8/18	41.27	85.37	126.51	36.18	64.45	104.71	42.39	74.03	97.36	33.21	81.11	88.89	14.07	32.46	20.82	-2.64	15.32	29.94	24.27	5.25
Mean	34.32	75.23	118.57	34.85	64.42	100.12	42.39	74.03	97.36	33.21	81.11	88.89	-1.44±6.25	19.3±12.76	19.46±15.05	3.33±7.24	1.62±5.21ab	21.78±12.81a	3.33±9.24	-7.25±4.76a
LYP9-PPH4-2016/8/18	32.07	83.12	102.51	28.25	76.02	139.24	44.9	69.14	74.74	29.58	62.55	91.97	13.52	9.34	-26.38	-28.57	20.22	37.16	8.42	32.89
YLY1-PPH4-2016/8/18	39.79	79.85	130.5	28.25	76.02	139.24	44.9	69.14	74.74	29.58	62.55	91.97	40.85	5.04	-6.28	-11.38	15.49	74.61	34.52	27.66
YLY2-PPH4-2016/8/18	39.04	68.01	110.23	40.77	72.57	95.16	44.9	69.14	74.74	29.58	62.55	91.97	-4.24	-6.28	15.84	-13.05	-1.63	47.48	31.98	8.73
YLY900-PPH4-2016/8/18	40.77	75.39	125.22	41.27	67.5	86.02	44.9	69.14	74.74	29.58	62.55	91.97	-1.21	11.69	45.57	-9.20	9.04	67.54	37.83	20.53
Mean	37.92	76.59	117.12	34.64	73.03	114.92	44.90	69.14	74.74	29.58	62.55	91.97	12.23±10.3	4.95±3.99	7.19±15.43	28.19±4.41	10.78±4.73b	56.7±8.68b	28.19±6.70	22.45±5.23b

TABLE 6
TRAITS OF DIFFERENT RICE VARIETIES WITH DIFFERENT TRANSPLANTING PLANT NUMBERS PER HILL IN 2016

2016-Variety	Plant height(cm)				Effective panicle number per hill (EPN)				Spikelets per panicle (SPP)			
	PPH1	PPH2	PPH3	PPH4	PPH1	1PPH2	PPH3	PPH4	PPH1	PPH2	PPH3	PPH4
LYP9	118.2±1.35De	116.73±3.92DEd	117.2±5.76DEFd	118.47±5.41CDEd	13.15±0.85Cc	13.95±0.94BCDbcd	14.8±0.68BCc	14.6±1.20BCDc	168.35±16.73BCb	130.62±5.01ABb	175.45±7.67Bb	174.54±4.42CDbc
YLY1	120.07±1.23De	118.47±5.82DEde	121.8±3.08Fe	119.07±5.48DEde	14.95±0.78Cc	14.4±0.93BCDcd	15.25±1.17Cc	15.3±0.82CDcd	199.42±8.73Cc	140.97±3.54Bb	152.81±4.7ABb	165.47±7.35CDbc
R9311	110.67±1.03Cd	113.53±4.52CDcd	113.33±4.43CDc	116.07±3.9CDcd	10.3±0.57Bb	11.7±1.10Bb	11.85±0.86Bb	12.35±0.59Bb	138.37±6.87Bb	124.8±6.19ABb	128.18±5.02ABab	130.23±10.34ABCab
YLY2	119.93±1.01De	121.93±5.51Ee	119.53±2.8Efde	122.53±4.29Ee	11.6±0.57BCbc	13.85±0.89BCDbcd	15.55±0.79Cc	13.8±0.75BCbc	146.03±9.55Bb	194.45±12.35Cd	138.67±23.49ABab	156.82±19.44BCDb
YH2	100.47±1.21Bb	108.07±8.18Bb	107.6±7.57Bb	107.53±5.34Bb	11.55±0.83BCbc	14.15±1.02BCDbcd	14±0.90BCbc	12.2±0.60Bb	155.79±10.5Bb	134.53±13.94ABb	148.36±18.82ABb	118.14±6.1ABa
Y900	110.27±1.14Cd	117.8±4.2DEde	112.47±3.52Cc	113.93±3.41Cc	10.15±0.62ABb	12.55±0.76BCbc	12.1±0.68Bb	13.9±0.81BCbc	210.93±12.15Cc	269.15±25.05Dd	253.03±10.55Cc	243.46±15.25Ed
R900	87.87±1.25Aa	86.53±11.92Aa	91.6±5.94Aa	88.33±7.58Aa	7.65±0.54Aa	4.8±0.37Aa	4.95±0.30Aa	4.65±0.47Aa	227.15±10.53Cc	146.16±7.13Bb	159.82±19.97Bb	194±10.62Dc
HHZ	103.33±1.06BCbc	105.2±4.23Bb	105±4.81Bb	107.33±3.22Bb	16.9±0.85Dd	15.1±1.02CDd	15.45±0.99Cc	17.2±0.84Dd	138.29±7.82Bb	136.26±10.57Bb	161.46±8.01Bb	141.9±9.25ABCab
XWX17	106.27±1.21Cc	111.87±4.16Cc	117±4.63CDEd	117.67±2.55CDd	14.95±0.48CDc	15.95±0.94Dd	16.1±0.88Cc	13.95±0.54BCbc	97.79±9.3Aa	91.16±3.71Aa	101.54±9.26Aa	111.63±4.97Aa

2016-Variety	Seed set rate (SSR)				1000 grains weight (KGW)				Harvest index (HI)			
	PPH1	PPH2	PPH3	PPH4	PPH1	PPH2	PPH3	PPH4	PPH1	PPH2	PPH3	PPH4
LYP9	92.76±0.67EFde	89.3±0.92CDd	94.38±0.77Cc	90.54±1.63Dd	30.71±0.26Cd	29.58±0.26CDEd	28.71±0.18Dd	26.59±0.23Cc	0.48±0.02BCc	0.39±0.02Cc	0.52±0.02Dd	0.56±0.02EFf
YLY1	96.88±0.31FE	94.85±1.05Dd	93.48±1.14Cc	91.85±1.38Dd	29.21±0.32Cc	28.95±0.20CDcd	26.06±0.79Cc	26.83±0.22Ccd	0.55±0.01Cd	0.52±0.01Dd	0.48±0.02CDcd	0.45±0.02Dd
R9311	82.91±3.07BCc	76.14±2.25BCc	60.88±3.96Aa	68.38±4.22Bb	32.98±0.33De	31.42±0.18Ee	31.66±0.30Ee	32.01±0.19De	0.41±0.02Bb	0.32±0.02BCb	0.3±0.02Bb	0.29±0.02Bb
YLY2	92.65±1.21EFde	94.94±0.98Dd	86.2±6.2BCc	91.16±0.84Dd	27.18±0.17Bc	28.78±0.32CDcd	27.81±0.16CDd	27.01±0.47Cd	0.56±0.00Cd	0.53±0.01Dd	0.54±0.01Dde	0.51±0.02Eef
YH2	70.16±2.96Aa	66.51±2.84Bb	81.11±2.81BCbc	83.7±0.78CDc	24.21±0.13ABab	24.82±0.28Bb	25.9±0.60Cc	28.2±0.37Cd	0.35±0.03ABa	0.28±0.02Bb	0.34±0.02BCb	0.35±0.01Cc
Y900	89.81±1.33DEd	90.4±1.27CDd	89.62±1.37Cc	92.72±0.96Dd	25.49±0.20Bb	23.33±0.15Bb	23.4±0.09Bb	23.23±0.12Bb	0.54±0.02Ccd	0.54±0.02Dd	0.57±0.01De	0.58±0.01Ff
R900	72.36±1.60Aab	45.44±6.89Aa	54.08±3.83Aa	42.06±2.49Aa	22.94±0.60Aa	20.48±1.47Aa	19.72±0.93Aa	15.49±0.99Aa	0.3±0.02Aa	0.16±0.4Aa	0.15±0.02Aa	0.11±0.01Aa
HHZ	84.26±0.59CDc	82.77±1.92Ccd	91.46±0.69Cc	83.78±1.84CDc	27.07±0.27Bc	27.51±0.11Cc	24.73±0.25BCbc	23.67±0.60Bb	0.52±0.01Ccd	0.51±0.02Dd	0.55±0.01Dde	0.54±0.02EFf
XWX17	76.73±1.76ABb	79.9±1.11Cc	75.11±1.87Bb	82.1±1.42Cc	30.7±1.13Cd	30.34±0.66DEde	30.93±0.40Ee	31.78±0.73De	0.46±0.04BCbc	0.48±0.01Dd	0.45±0.02Cc	0.49±0.01DEe

2016-Variety	Yield (t/ha)			
	PPH1	PPH2	PPH3	PPH4
LYP9	7976.89±814.68Bb	8872.7±255.81Dd	9935.5±1007.95EFe	8172.75±1818.77CDcd
YLY1	10622.28±183.14Cc	8381.65±148.71CDd	8781.04±446.98DEd	9026.08±1122.26DEd
R9311	6814.44±529.74Bb	7211.25±550.77Cc	5145.17±88.1Bb	4366.81±350.33Bb
YLY2	11137.38±288.89Cc	10215.94±455.02DEf	8493.25±277.56Dd	7777.85±1030.61Ccd
YH2	7028.11±512.07Bb	5595.4±301.87Bb	6921.27±592.71Cc	5960.41±870.83Cbc
Y900	10702.41±668.32Cc	11641.02±412.55Eg	11097.31±485.73Ff	10668.07±974.49Ed
R900	2777.67±297.41Aa	1976.42±213.67Aa	2564±423.93Aa	1976.42±790.49Aa
HHZ	9747.4±517.28Cc	10575.58±491.89Efg	10575.58±617.61Fef	9008.56±638.14DEd
XWX17	7095.45±332.45Bb	6804.2±185.8BCc	6799.17±342.31Cc	6810.72±211.97Cc

3.2 EPN and SPP advantages in hybrid rice under varying transplanting densities:

EPN is a key determinant of rice yield, showing significant variation among the studied varieties. In 2015, under transplanting densities of 1, 1, 2, and 4 plants per hill, the HBP for EPN in hybrid rice ranged from 35.93% to 43.29%. The HCK1 (HHZ) values ranged from -18.98% to 9.81%, while HCK2 (XW17) values ranged from -11.19% to -0.46% (**Table A5, Figure A2**). In 2016, with transplanting densities of 1, 2, 3, and 4 plants per hill, the HBP for EPN in hybrid rice increased significantly, ranging from 26.48% to 63.54%. The HCK1 (HHZ) values ranged from -26.26% to -6.63%, while HCK2 (XW17) values varied from -16.64% to 3.23% (**Tables 6, 7, Figure 2**). These results suggest that transplanting density influences EPN in hybrid rice, restorer lines, and inbred varieties. EPN increased significantly with higher transplanting densities, reaching its highest value at four plants per hill in 2015 and at two plants per hill in 2016 for the inbred variety XW17. The HBP for EPN remained positive, whereas the HCK for EPN was negative, although the trend was not pronounced.

SPP is another critical yield component, with substantial differences among the studied rice varieties. The restorer line R900 exhibited the highest SPP, while the inbred variety XW17 had the lowest. In 2015, under transplanting densities of 1, 1, 2, and 4 plants per hill, the HBP for SPP in hybrid rice ranged from 1.92% to 24.6%. The HCK1 (HHZ) values ranged from 8.65% to 36.72%, while HCK2 (XW17) values varied from 31.23% to 104.3% (**Table A5, Figure A2**). In 2016, with transplanting densities of 1, 2, 3, and 4 plants per hill, the HBP for SPP in hybrid rice increased to 13.1%–36.58%. The HCK1 (HHZ) values ranged from 11.48% to 34.89%, while HCK2 (XW17) values spanned from 65.79% to 101.62% (**Tables 6, 7, Figure 2**). These findings indicate that transplanting density influences SPP across different rice varieties. In 2015, SPP was highest at one plant per hill and lower at two and four plants per hill, a trend that persisted in 2016. The heterosis for SPP in hybrid rice was significant but declined as transplanting density increased.

3.3 Strong heterosis for SSR but negative effects on KGW across transplanting densities:

SSR is another essential yield-related trait, displaying significant variation among the studied rice varieties. In 2015, under transplanting densities of 1, 1, 2, and 4 plants per hill, the HBP for SSR in hybrid rice ranged from 2.89% to 5.43%. The HCK1 (HHZ) values ranged from -3.68% to 2.14%, while HCK2 (XW17) values varied from 1.59% to 10.14% (**Table A5, Figure A2**). In 2016, with transplanting densities of 1, 2, 3, and 4 plants per hill, the HBP for SSR in hybrid rice increased substantially, reaching 21.23%–49.02%. The HCK1 (HHZ) values ranged from -0.59% to 11.6%, while HCK2 (XW17) values varied from 11.53% to 21.24% (**Tables 6, 7, Figure 2**). The SSR of hybrid rice and the inbred variety HHZ was significantly higher than that of other varieties. While transplanting density had a limited impact on SSR in hybrid rice and inbred varieties, it significantly influenced restorer lines. As transplanting density increased, SSR exhibited a decreasing trend. The heterosis for SSR in hybrid rice was evident in 2015 and 2016, demonstrating a clear effect of transplanting density on this trait.

KGW, another critical yield component, exhibited considerable variation across rice varieties. The restorer line R900 had the smallest KGW, while 9311 had the highest. In 2015, under transplanting densities of 1, 1, 2, and 4 plants per hill, the HBP for KGW in hybrid rice ranged from -11.59% to -6.61%. The HCK1 (HHZ) values were between 4.71% and 9.54%, while HCK2 (XW17) values ranged from -17.16% to -14.06% (**Table A5, Figure A2**). In 2016, with transplanting densities of 1, 2, 3, and 4 plants per hill, the HBP for KGW in hybrid rice further declined from -25.09% to -14.23%. The HCK1 (HHZ) values ranged from -2.04% to 3.42%, while HCK2 (XW17) values varied between -24.54% and -10.39% (**Tables 6, 7, Figure 2**). These results suggest that the KGW of hybrid rice, restorer lines, and inbred varieties remained relatively high, with transplanting density exerting minimal influence. The HBP for KGW in hybrid rice showed a consistent negative trend in 2015 and 2016, whereas HCK1 (HHZ) exhibited a positive advantage, and HCK2 (XW17) displayed a negative advantage. As transplanting density increased, both HBP and HCK for KGW in hybrid rice exhibited a downward trend.

TABLE 7
HETEROSIS FOR TRAITS OF HYBRID RICE UNDER DIFFERENT TRANSPLANTING PLANT NUMBERS PER HILL IN 2016

2016-variety	Hybird rice（PH）	Restore line（PH）	HHZ（PH）	XW17(PH）	HBP（%）	HCK1 (%)	HCK2 (%)
LYP9-PPH1	118.2	110.67	103.33	106.27	6.8	10.39	11.23
YLY1-PPH1-	120.07	110.67	103.33	106.27	8.49	9.62	12.99
YLY2-PPH1-	119.93	100.47	103.33	106.27	19.37	19.37	12.85
YLY900-PPH1	110.27	87.87	103.33	106.27	25.49	6.72	3.76
Mean	117.12	102.42	103.33	106.27	15.04±4.46	11.53±2.73	10.21±2.19b
LYP9-PPH2	116.73	115.53	105.2	111.87	1.04	10.96	4.34
YLY1-PPH2-	118.47	115.53	105.2	111.87	2.55	12.61	5.9
YLY2-PPH2-	121.93	108.07	105.2	111.87	12.83	15.9	8.99
YLY900-PPH2	117.8	86.53	105.2	111.87	36.14	11.98	5.3
Mean	118.73	106.42	105.2	111.87	13.14±8.10	12.86±1.07	6.13±1.01b
LYP9-PPH3	117.2	113.33	105	117	3.42	11.62	0.17
YLY1-PPH3-	121.8	113.33	105	117	7.47	16	4.1
YLY2-PPH3-	119.53	107.6	105	117	11.09	13.84	2.16
YLY900-PPH	112.47	91.6	105	117	22.78	7.11	-3.87
Mean	117.75	106.47	105	117	11.19±4.17	12.14±1.90	0.64±1.70a
LYP9-PPH4	118.47	116.07	107.33	117.67	2.07	10.38	0.68
YLY1-PPH4-	119.07	116.07	107.33	117.67	2.59	10.94	1.19
YLY2-PPH4-	122.53	107.53	107.33	117.67	13.95	14.16	4.13
YLY900-PPH4	113.93	88.33	107.33	117.67	28.98	6.15	-3.18
Mean	118.5	107	107.33	117.67	11.90±6.32	10.41±1.65	0.71±1.50a
2016-variety	**Hybird rice（EPN）**	**Restore line（EPN）**	**HHZ （EPN）**	**XW17（EPN）**	**HBP（%）**	**HCK1 (%)**	**HCK2 (%)**
LYP9-PPH1	13.15	10.3	16.9	14.95	27.67	-22.19	-12.04
YLY1-PPH1-	14.95	10.3	16.9	14.95	45.15	-11.54	0
YLY2-PPH1-	11.6	11.55	16.9	14.95	0.43	-31.36	-22.41
YLY900-PPH1	10.15	7.65	16.9	14.95	32.68	-39.94	-32.11
Mean	12.46	9.95	16.9	14.95	26.48±9.43	-26.26±3.05a	--16.64±6.9a

LYP9-PPH2	13.95	11.7	15.1	15.95	19.23	-7.62	-12.54
YLY1-PPH2-	14.4	11.7	15.1	15.95	23.08	-4.64	-9.72
YLY2-PPH2-	13.85	14.15	15.1	15.95	-2.12	-8.28	-13.17
YLY900-PPH2	12.55	4.8	15.1	15.95	161.46	-16.89	-21.32
Mean	13.69	10.59	15.1	15.95	50.41±37.43	-9.35±2.63b	-14.18±2.49a
LYP9-PPH3	14.8	11.85	15.45	16.1	24.89	-4.21	-8.07
YLY1-PPH3-	15.25	11.85	15.45	16.1	28.69	-1.29	-5.28
YLY2-PPH3-	15.55	14	15.45	16.1	11.07	0.65	-3.42
YLY900-PPH	12.1	4.95	15.45	16.1	144.44	-21.68	-24.84
Mean	14.43	10.66	15.45	16.1	52.28±30.95	-6.63±5.11b	-10.40±4.91ab
LYP9-PPH4	14.6	12.35	17.2	13.95	18.22	-15.12	4.66
YLY1-PPH4-	15.3	12.35	17.2	13.95	23.89	-11.05	9.68
YLY2-PPH4-	13.8	12.2	17.2	13.95	13.11	-19.77	-1.08
YLY900-PPH4	13.9	4.65	17.2	13.95	198.92	-19.19	-0.36
Mean	14.4	10.39	17.2	13.95	63.54±45.18	-16.28±2.03ab	3.23±2.50b
2016-variety	**Hybird rice (GNP)**	**Restore line (GNP)**	**HHZ (GNP)**	**XW17 (GNP)**	**HBP（%）**	**HCK1 (%)**	**HCK2 (%)**
LYP9-PPH1	168.35	138.37	138.29	97.79	21.67	21.74	72.15
YLY1-PPH1-	199.42	138.37	138.29	97.79	44.12	44.2	103.93
YLY2-PPH1-	146.03	155.79	138.29	97.79	-6.26	5.6	49.33
YLY900-PPH1	210.93	227.15	138.29	97.79	-7.14	52.53	115.7
Mean	181.18	164.92	138.29	97.79	13.10±12.32	31.02±10.68	85.28±15.11
LYP9-PPH2	130.62	124.8	136.26	91.16	4.66	-4.14	43.29
YLY1-PPH2-	140.97	124.8	136.26	91.16	12.96	3.46	54.64
YLY2-PPH2-	194.45	134.53	136.26	91.16	44.54	42.71	113.31
YLY900-PPH2	269.15	146.16	136.26	91.16	84.15	97.53	195.25
Mean	183.8	132.57	136.26	91.16	36.58±18.03	34.89±23.27	101.62±34.78
LYP9-PPH3	175.45	128.18	161.46	101.54	36.88	8.66	72.79
YLY1-PPH3-	152.81	128.18	161.46	101.54	19.22	-5.36	50.49
YLY2-PPH3-	138.67	148.36	161.46	101.54	-6.53	-14.11	36.57
YLY900-PPH3	253.03	159.82	161.46	101.54	58.32	56.71	149.19
Mean	179.99	141.14	161.46	101.54	26.97±13.73	11.48±15.79	77.26±25.11

LYP9-PPH4	174.54	130.23	141.9	111.63	34.02	23	56.36
YLY1-PPH4-	165.47	130.23	141.9	111.63	27.06	16.61	48.23
YLY2-PPH4-	156.82	118.14	141.9	111.63	32.74	10.51	40.48
YLY900-PPH4	243.46	194	141.9	111.63	25.49	71.57	118.1
Mean	185.07	143.15	141.9	111.63	29.83±2.09	30.42±13.95	65.79±17.73
2016-variety	**Hybird rice (SSR %)**	**Restore line (SSR %)**	**HHZ (SSR %)**	**XW17 (SSR)**	**HBP（%）**	**HCK1 (%)**	**HCK2 (%)**
LYP9-PPH1	92.76	82.91	84.26	76.73	11.88	10.09	20.89
YLY1-PPH1-	96.88	82.91	84.26	76.73	16.85	14.98	26.26
YLY2-PPH1-	92.65	70.16	84.26	76.73	32.06	9.96	20.75
YLY900-PPH1	89.81	72.36	84.26	76.73	24.12	6.59	17.05
Mean	93.03	77.09	84.26	76.73	21.23±4.4	10.4±1.73b	21.24±1.9c
LYP9-PPH2	89.3	76.14	82.77	79.9	17.28	7.89	11.76
YLY1-PPH2-	94.85	76.14	82.77	79.9	24.57	14.59	18.71
YLY2-PPH2-	94.94	66.51	82.77	79.9	42.75	14.7	18.82
YLY900-PPH2	90.4	45.44	82.77	79.9	98.94	9.22	13.14
Mean	92.37	66.06	82.77	79.9	45.89±18.48	11.6±1.78b	15.61±1.84ab
LYP9-PPH3	94.38	60.88	91.46	75.11	55.03	3.19	25.66
YLY1-PPH3-	93.48	60.88	91.46	75.11	53.55	2.21	24.46
YLY2-PPH3-	86.2	81.11	91.46	75.11	6.28	-5.75	14.77
YLY900-PPH3	89.62	54.08	91.46	75.11	65.72	-2.01	19.32
Mean	90.92	64.24	91.46	75.11	45.14±13.24	-0.59±2.06a	21.05±2.51c
LYP9-PPH4	90.54	68.38	83.78	82.1	32.41	8.07	10.28
YLY1-PPH4-	91.85	68.38	83.78	82.1	34.32	9.63	11.88
YLY2-PPH4-	91.16	83.7	83.78	82.1	8.91	8.81	11.04
YLY900-PPH4	92.72	42.06	83.78	82.1	120.45	10.67	12.94
Mean	91.57	65.63	83.78	82.1	49.92±24.5	9.3±0.56b	11.53±0.57b
2016-variety	**Hybird rice (KGW)**	**Restore line (KGW)**	**HHZ (KGW)**	**XW17 (KGW g)**	**HBP（%）**	**HCK1 (%)**	**HCK2 (%)**
LYP9-PPH1	30.71	32.98	27.07	30.7	-6.88	13.45	0.03
YLY1-PPH1-	29.21	32.98	27.07	30.7	-11.43	7.91	-4.85
YLY2-PPH1-	27.18	32.98	27.07	30.7	-17.59	0.41	-11.47
YLY900-PPH1	22.94	32.98	27.07	30.7	-30.44	-15.26	-25.28

Mean	27.51	32.98	27.07	30.7	-16.59±5.11	1.63±6.23	-10.39±2.75
LYP9-PPH2	29.58	31.42	27.51	30.34	-5.86	7.52	-2.5
YLY1-PPH2-	28.95	31.42	27.51	30.34	-7.86	5.23	-4.58
YLY2-PPH2-	28.78	31.42	27.51	30.34	-8.4	4.62	-5.14
YLY900-PPH2	20.48	31.42	27.51	30.34	-34.82	-25.55	-32.5
Mean	26.95	31.42	27.51	30.34	-14.23±6.88	-2.04±7.86	-11.18±7.13
LYP9-PPH3	28.71	31.66	24.73	30.93	-9.32	16.09	-7.18
YLY1-PPH3-	26.06	31.66	24.73	30.93	-17.69	5.38	-15.75
YLY2-PPH3-	27.81	31.66	24.73	30.93	-12.16	12.45	-10.09
YLY900-PPH3	19.72	31.66	24.73	30.93	-37.71	-20.26	-36.24
Mean	25.58	31.66	24.73	30.93	-19.22±6.40	3.42±8.2	-17.31±6.55
LYP9-PPH4	26.59	32.01	23.67	31.78	-16.93	12.34	-16.33
YLY1-PPH4-	26.83	32.01	23.67	31.78	-16.18	13.35	-15.58
YLY2-PPH4-	27.01	32.01	23.67	31.78	-15.62	14.11	-15.01
YLY900-PPH4	15.49	32.01	23.67	31.78	-51.61	-34.56	-51.26
Mean	23.98	32.01	23.67	31.78	-25.09±8.85	1.31±11.96	-24.54±8.91
2016-variety	**Hybird rice (HI)**	**Restore line (HI)**	**HHZ (HI)**	**XW17 (HI)**	**HBP (%)**	**HCK1(%)**	**HCK2 (%)**
LYP9-PPH1	0.48	0.41	0.52	0.46	17.07	-7.69	4.35
YLY1-PPH1-	0.55	0.41	0.52	0.46	34.15	5.77	19.57
YLY2-PPH1-	0.56	0.35	0.52	0.46	60	7.69	21.74
YLY900-PPH1	0.54	0.3	0.52	0.46	80	3.85	17.39
Mean	0.53	0.37	0.52	0.46	47.8±13.89	2.4±3.46	15.76±3.91
LYP9-PPH2	0.39	0.32	0.51	0.48	21.88	-23.53	-18.75
YLY1-PPH2-	0.52	0.32	0.51	0.48	62.5	1.96	8.33
YLY2-PPH2-	0.53	0.28	0.51	0.48	89.29	3.92	10.42
YLY900-PPH2	0.54	0.16	0.51	0.48	237.5	5.88	12.5
Mean	0.5	0.27	0.51	0.48	102.79±46.99	-2.94±6.91	3.13±7.34
LYP9-PPH3	0.52	0.3	0.55	0.45	73.33	-5.45	15.56
YLY1-PPH3-	0.48	0.3	0.55	0.45	60	-12.73	6.67
YLY2-PPH3-	0.54	0.34	0.55	0.45	58.82	-1.82	20
YLY900-PPH3	0.57	0.15	0.55	0.45	280	3.64	26.67

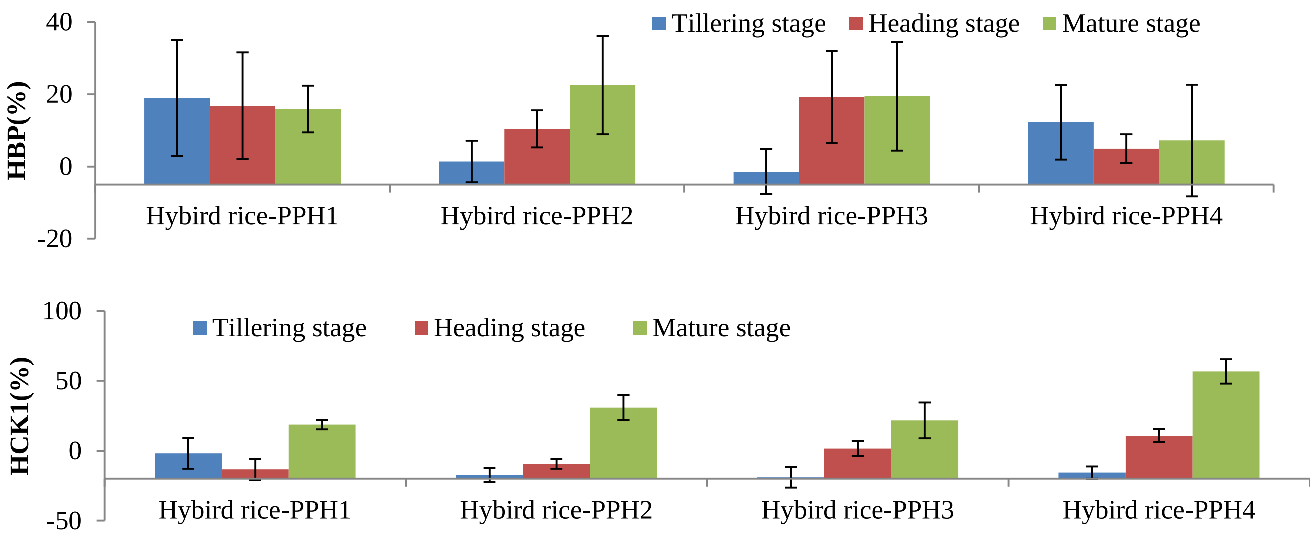
Mean	0.53	0.27	0.55	0.45	118.04±54.09	-4.09±3.43	17.22±4.19
LYP9-PPH4	0.56	0.29	0.54	0.49	93.1	3.7	14.29
YLY1-PPH4-	0.45	0.29	0.54	0.49	55.17	-16.67	-8.16
YLY2-PPH4-	0.51	0.35	0.54	0.49	45.71	-5.56	4.08
YLY900-PPH4	0.58	0.11	0.54	0.49	427.27	7.41	18.37
Mean	0.53	0.26	0.54	0.49	155.32±91.23	-2.78±5.37	7.14±5.92
2016-variety	**Hybird rice (Yield)**	**Restore line(Yield)**	**HHZ(Yield)**	**XW17 (Yield)**	**HBP(%)**	**HCK1(%)**	**HCK2 (%)**
LYP9-PPH1	7976.89	6814.44	9747.4	7095.45	17.06	-18.16	12.42
YLY1-PPH1-	10622.28	6814.44	9747.4	7095.45	55.88	8.98	49.71
YLY2-PPH1-	11137.38	7028.11	9747.4	7095.45	58.47	14.26	56.97
YLY900-PPH1	10702.41	6814.44	9747.4	7095.45	57.05	9.8	50.83
Mean	10109.74	6867.86	9747.4	7095.45	47.12±61.15	3.72±7.39	42.48±10.15
LYP9-PPH2	8872.7	7211.25	10575.58	6804.2	23.04	-16.1	30.4
YLY1-PPH2-	8381.65	7211.25	10575.58	6804.2	16.23	-20.75	23.18
YLY2-PPH2-	10215.94	5595.4	10575.58	6804.2	82.58	-3.4	50.14
YLY900-PPH2	11641.02	7211.25	10575.58	6804.2	61.43	10.07	71.09
Mean	9777.83	6807.29	10575.58	6804.2	45.82±113.08	-7.54±6.92	43.7±5.1
LYP9-PPH3	9935.5	5145.17	10575.58	6799.17	93.1	-6.05	46.13
YLY1-PPH3-	8781.04	5145.17	10575.58	6799.17	70.67	-16.97	29.15
YLY2-PPH3-	8493.25	6921.27	10575.58	6799.17	22.71	-19.69	24.92
YLY900-PPH3	11097.31	5145.17	10575.58	6799.17	115.68	4.93	63.22
Mean	9576.78	5589.2	10575.58	6799.17	75.54±69.23	-9.44±5.63	40.85±8.75
LYP9-PPH4	8172.75	4366.81	9008.56	6810.72	87.16	-9.28	20
YLY1-PPH4-	9026.08	4366.81	9008.56	6810.72	106.7	0.19	32.53
YLY2-PPH4-	7777.85	5960.41	9008.56	6810.72	30.49	-13.66	14.2
YLY900-PPH4	10668.07	4366.81	9008.56	6810.72	144.3	18.42	56.64
Mean	8911.19	4765.21	9008.56	6810.72	92.16±92.67	-1.08±7.11	30.84±9.41

PPH1,2,3,4- 1,2.3,4 plants per hill

3.4 Hybrid rice demonstrates a noticeable HI and Yield advantage across transplanting densities:

HI is a critical yield trait, varying significantly among different rice varieties. Hybrid rice and the inbred variety HHZ exhibited relatively high HI values, whereas restorer lines had consistently low HI. In 2015, under transplanting densities of 1, 1, 2, and 4 plants per hill, the HBP for HI in hybrid rice ranged from 19.79% to 24.75%. The HCK1 (HHZ) values ranged from -12.07% to -8.19%, while HCK2 (XW17) varied from -3.77% to 2.04% (**Table A5, Figure A2**). In 2016, with transplanting densities of 1, 2, 3, and 4 plants per hill, the HBP for HI in hybrid rice increased significantly, ranging from 47.8% to 155.32%. The HCK1 (HHZ) values ranged from -4.09% to 2.4%, while HCK2 (XW17) ranged from 3.13% to 17.22% (**Tables 6, 7, Figure 2**). These results indicate that hybrid rice and HHZ maintain relatively high HI values, with transplanting density having minimal influence across different varieties. The HBP for HI in hybrid rice exhibited strong positive heterosis in both years. Notably, in 2016, HBP for HI increased with the number of transplanted plants. While HCK2 (XW17) displayed positive heterosis, HCK1 (HHZ) exhibited negative heterosis. Overall, transplanting density had a limited impact on HBP for HI in hybrid rice.

Rice yield, a comprehensive expression of multiple yield-contributing traits, varied significantly across the studied varieties. Hybrid rice and the inbred variety HHZ exhibited relatively high yields, while restorer lines had consistently low yields. In 2015, under transplanting densities of 1, 1, 2, and 4 plants per hill, the HBP for hybrid rice yield ranged from 39.64% to 58.2%. The HCK1 (HHZ) values ranged from -19.6% to 8.89%, while HCK2 (XW17) ranged from 23.17% to 41.49% (**Table A5, Figure A2**). In 2016, with transplanting densities of 1, 2, 3, and 4 plants per hill, the HBP for hybrid rice yield increased further, reaching 45.82%–92.16%. The HCK1 (HHZ) values ranged from -9.44% to 3.72%, while HCK2 (XW17) ranged from 30.84% to 42.48% (**Tables 6, 7, Figure 2**). These findings indicate that transplanting density significantly influenced yield. Hybrid rice achieved relatively high yields at 1 and 2 plants per hill, but yields declined as transplanting density increased. In contrast, the inbred varieties HHZ and XW17 showed higher yields at 2 and 3 plants per hill. The maximum yield of HHZ, recorded at 9551.5 kg ha^{-1} with 4 plants per hill in 2015, suggests that increasing transplanting density can enhance inbred rice yield to some extent. The HBP for hybrid rice yield demonstrated significant positive heterosis in both years. While HCK2 (XW17) also exhibited positive heterosis, HCK1 (HHZ) showed negative heterosis. The effect of transplanting density on yield heterosis was more pronounced in 2015, whereas in 2016, yield heterosis increased with higher transplanting densities.



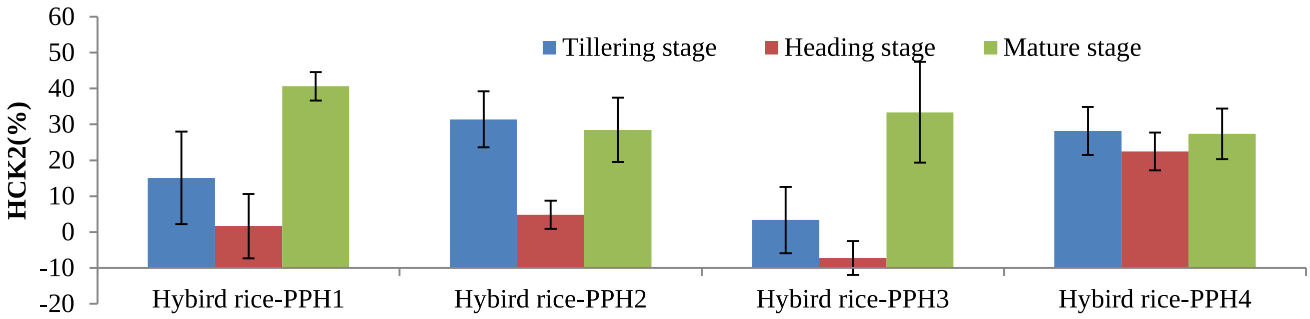


FIGURE 1: Heterosis for dry matter accumulation in hybrid rice under different transplanting densities at various growth stages in 2016, HBP: High-parent heterosis, HCK: Standard heterosis, PPH1,2,3,4: 1,2,3,4 plants per hill. Within each column, different letters indicate statistically significant differences: lowercase letters ($p \leq 0.05$) and uppercase letters ($p \leq 0.01$), as determined by the least significant difference (LSD) test.

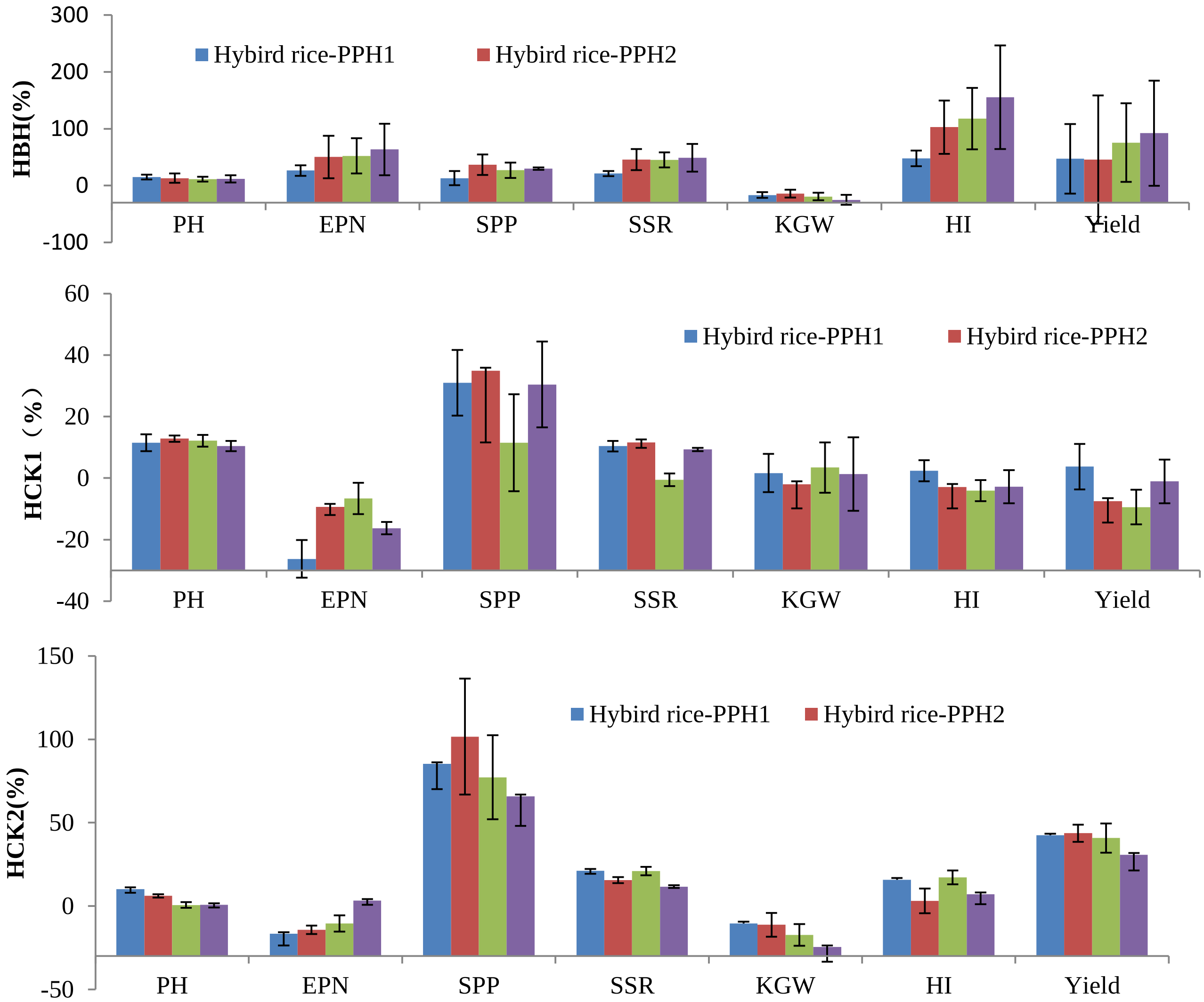


FIGURE 2. Heterosis for agronomic traits of hybrid rice under different transplanting densities in 2016, PPH1,2,3,4: 1,2,3,4 plants per hill, PH: Plant height, EPN: effective panicle number per hill, SPP: spikelets per panicle, SSR: seed setting rate, KGW: 1000-grain weigh, HI: Harvest index

IV. DISCUSSION

4.1 Influence of transplanting density on rice yield:

This study demonstrated that hybrid rice varieties achieved optimal yields with 1–2 plants per hill, while inbred varieties performed best with 3–4 plants per hill under a transplanting spacing of 19.8 cm × 26.4 cm. These findings provide a theoretical foundation for breeding strategies, high-yield cultivation, and the large-scale adoption of hybrid rice. Previous studies have reported similar results; for example, when two-line hybrid rice JLY534 was transplanted at 18 cm × 30 cm with 1–6 plants per hill, yields were highest with 1–2 plants per hill, with significant effects on EPN, SPP, SSR, and KGW [17]. Under a 30 cm × 12.6 cm transplanting specification, yields of both hybrid and inbred varieties initially increased with transplanting density before declining, with the optimal number per hill being 3–4 for hybrid rice and 4–5 for inbred rice [18].

Hybrid rice achieved its highest yield when planted with two seedlings per hill at a spacing of 30 cm × 25 cm × 16.67 cm (2.25 × 10^5 hills ha^{-1}), suggesting that this configuration is most suitable. Transplanting experiments under different fertilizer conditions revealed that high yields were achieved with 3–5 plants per hill at 25 cm × 17 cm (2.35 × 10^5 hills ha^{-1})[19]. Consistent with these findings, our results indicate that super hybrid rice yields declined as the number of transplanted plants per hill increased. Inbred variety HHZ exhibited peak yields when transplanted with four plants per hill in 2015 and with two or three plants per hill in 2016. While hybrid rice displayed clear yield advantages over restorer lines and inbred varieties, no consistent pattern emerged regarding its response to transplanting density.

4.2 Effects of transplanting density on dry matter accumulation, EPN, SPP, and SSR:

Our study revealed that transplanting density significantly affected BPH, PH, SPP, SSR, HI, and yield in hybrid rice. Hybrid varieties thrived under optimal planting densities but showed reduced lodging resistance under high-density conditions [20]. *Indica* hybrid rice, which typically exhibits high tillering potential, benefits from an appropriate number of transplants per hill, optimizing tiller utilization and balancing individual and population growth dynamics [21]. When transplanting density exceeded five plants per hill, the effective tiller percentage declined sharply, with 2–4 plants per hill identified as optimal [22, 23].

As transplanting density increased, the leaf area index and dry matter accumulation rose during the tillering stage but declined at maturity. The most efficient light use and biomass production occurred with 2–3 plants per hill; beyond this threshold, further increases in seedling numbers provided no additional benefit [14]. High-yielding hybrid rice is characterized by large panicles and significant above-ground dry matter accumulation, which supports sustained productivity [24, 25]. Transplanting experiments confirmed that 3–5 plants per hill at 25 cm × 17 cm (2.35 ×10^4 hills ha^{-1}) produced high yields across fertilizer conditions [19].

Direct-seeding experiments showed that reducing the sowing rate of hybrid rice from 240 grains m^{-2} to 60 grains m^{-2} did not affect yield, whereas inbred varieties suffered yield losses due to insufficient tillering and reduced panicle formation[26]. Studies on *Japonica* hybrid rice III You 98 indicated that planting density strongly influenced yield, while PH, panicle length, and KGW remained relatively stable. Close spacing and transplanting two seedlings per hill were optimal for maximizing yield [27]. Machine transplanting trials at 30 cm × 12 cm found that increasing planting density boosted effective panicle numbers but reduced sink capacity per hill. Although SPP decreased, transplanting at 30 and 35 days of seedling age improved yield, whereas seedling age of 25 days had minimal impact on yield under increased planting density[28].

Our findings demonstrated that the advantages of hybrid rice in dry matter accumulation and effective panicle number declined as transplanting density increased. Additionally, HCK for SPP decreased with higher planting densities, mirroring trends observed in SSR. These results suggest that effective panicle number and SPP are key contributors to hybrid rice yield. Moreover, lodging risks increased significantly when the number of transplanted plants per hill exceeded 3–4, underscoring the importance of optimized spacing to balance yield potential and structural stability. With the development of direct seeding machine and rice seeding transplanter, controlling the amount of seeds, density, and number of transplanted seedlings has become an important challenge and a key control technology, this result is of great significance for improving yield.

V. CONCLUSION

Under the spatial planting arrangement of 19.8 cm × 26.4 cm, super hybrid rice demonstrated significant advantages in dry matter accumulation, PH, SPP, SSR, HI, and overall yield. EPN showed a moderate advantage, whereas KGW exhibited a slight disadvantage. For optimal yield without compromising seed quantity, transplanting 1–2 plants per hill is recommended for hybrid rice, while 3–4 plants per hill are suitable for inbred rice. The investigation of biological and yield traits of hybrid rice, restorer lines and conventional varieties under the same cultivation conditions can early determine the strength and weakness of heterosis of hybrid rice.

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Genetic Diversity of Potato (*Solanum tuberosum* L.) Cultivars Grown in Lesotho as Determined by Morphological Markers

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Abstract— *Irish potato is the only tuber crop grown by farmers in Lesotho, particularly in the foothills where environment is conducive for its growth and high yield. Potato seeds are imported from South Africa without verifying for authenticity, fraudulence and intellectual property rights. The objectives of the study were to: (i) estimate genetic distance among potato cultivars using morphological markers, (ii) determine discriminatory power of morphological markers in distinguishing potato cultivars. The study was conducted at National University of Lesotho experimental farm, Roma. Experiment was laid out using Randomized Complete Block Design with eight treatments and three replications. Treatments were cultivars; Mondial, Panamera, Taurus, Tyger, Tyson, Valor, Avalanche and Innovator. Data on 21 markers were collected using potato descriptor, thereafter analyzed using Genstat (Version 17) to perform cluster analysis and principal component analysis. Results of cluster analysis revealed variability among potato cultivars. Cultivars constituted 1 major group, which in turn divided into two sub-group. Two sub-groups further sub-divided three times forming sub-subgroups and outliers. First six principal components contributed 97% of variation among cultivars. Characters with high discriminatory power were marketable tubers, root fresh weight, tuber fresh weight, number of main stems, leaf dry weight, leaf fresh weight and total yield. In conclusion, cluster analysis has group cultivars according to their similarities and principal component analysis revealed characters with high discriminatory power.*

Keywords— Cluster Analysis; Genetic Diversity; Principal Component Analysis; Solanum Tuberosum L.

I. INTRODUCTION

Irish Potato (*Solanum tuberosum* L.) is originated from Peru, Bolivia and Andes in the Western South America [1]. Peru is considered as the center of origin, diversity and its wild relatives [2,3]. They were domesticated in the Andes and Southern Peru approximately 10 000 years ago [2,4]. Potatoes were introduced by Spaniards from Peru to Spain during trading, after which it was introduced in Europe where it became an important food crop in Ireland. Southern and Eastern Asia also showed the most rapid expansion over the past century [5]. Since then, its world-wide distribution increased tremendously making it the fourth largest starchy food crop following wheat, rice and maize. China is now the largest potato producing country in the world with the total annual yield of 60 million tons on 4 million ha and productivity of 15 tons ha^{-1} [6]. Approximately 85% of this potato is produced in the Northern part of China because of low temperature and suitability for growing potato crop [7].

Irish Potato crop is an annual, herbaceous dicotyledonous commonly propagated vegetatively, although it can also be propagated through seeds known as true potato seeds. Nonetheless, it can be grown as a perennial in selected environments [8]. Morphologically, potato can be characterized by erect stem which grows up to a height of one meter with alternate compound leaves of three to five pairs of leaflets arranged in a downward position [9]. Potato can be distinguished by its ability to develop tubers under short days and cool nights, and knowledge of genetic diversity, identification and characterization of cultivars provides an informative tool for the detection of duplicates in the collection, effective extension, better characterization and use in breeding programs [10]. In addition, characterization of potato genetic diversity is also important for tracing fraud, duplication, violation of cultivar protection, intellectual property right and ascertaining proper use of trademark [11,12].

In the past, morphological characterization was the most powerful tool in description, classification and evaluation of genetic resources. With time, morphological was superseded by biochemical and DNA-based molecular markers [10]. Nonetheless, morphological markers are still a powerful method where genetic distance of cultivars are far apart, and has a limitation where cultivars are closely related and share parentage

In the beginning of the past century, characterization was accomplished in potatoes using morphological markers, even though these markers were complex and greatly influenced by the environment [13,14]. In morphological characterization, descriptor for potato is available and compiled by International Plant Genetic Resource Unit of Food and Agriculture Organization (1982) to guide throughout the process. Descriptor is based on morphological traits such as leaf, stem, flower and tuber characteristics. Data regarding morphological characterization are generated throughout the growing season as potato cultivars are growing under field conditions [15], after which appropriate statistical tool is applied for analysis and virtualization leading to better comprehension.

All potato cultivars grown by farmers in Lesotho are brought from South Africa, which in turn obtain them from overseas or breed them within the country. They are imported into the country of Lesotho without following proper protocols of evaluating for distinctness, registration and adaptability. No method of characterization of potato has been established to date. As a result, some cultivars are mistaken for others, fraudulence is committed by people who multiply the seeds and sell them without a license from the owner, retailers use a different name for the same cultivar to disguise as if they are the ones breeding them and lastly, some are not easy to distinguish by visual appraisal. At the end of the day, such closely related cultivars are mixed when planting, thereby losing their distinctness and other economically important traits. This study is therefore undertaken with the following objectives; (i) to estimate genetic distance among eight potato cultivars using morphological markers, (ii) to determine the discriminatory power of the different morphological markers in distinguishing potato cultivars.

II. MATERIALS AND METHODS

2.1 Study area:

The study was conducted at National University of Lesotho experimental farm which is domiciled in Roma valley, about 34 km Southeast of Maseru, capital city of Lesotho. Lesotho is situated in Southern African region. The coordinates are 29°26’’48’S latitude and 27°42’’12’91E longitude. The altitude is 1,610 m above sea level.

Soils within the Roma valley are predominantly Berea and Tsiki series [16]. Berea series consists of fine-loamy, mixed, mesic family of Plinthaquic Dystrochrepts, with gradient of ≤ 2% slope. Tsiki comprises soil texture ranges from sandy to loamy, with sand content ranging from 50.8% to 67.7%, silt from 13.3% to 35.9% and clay from 13.3% to 20 %. Soil pH ranges from 5.02 to 5.22 (slightly acidic), organic matter ranges from 2.5 to 4.5 % [17].

Climate is temperate with average annual precipitation of 850mm, of which approximately 85% of it occurs from October reaching a peak in February, after which it declines rapidly to April [18]. Winter season is dry and cold with extreme low temperature of -100°C. Summer season is hot and humid, with highest temperature of 35.5°C in the lowlands and 24°C in the highlands [19]. High winds of up to 20 meters per second sometimes occur during summer season. Thunderstorms, frost, snow and hailstorms are experienced in Roma area [20].

2.2 Experimental Design:

Eight potato cultivars used in this study were obtained from Wesgrow Potatoes (Pty) Ltd located at Christiana in South Africa. It is a reputable company known for production of high-quality potato seeds that are disease free. The potato cultivars used were Mondial, Panamera, Taurus, Tiger, Tyson, Valor, Avalanche and Innovator.

The experiment was laid out using Randomized Complete Block Design (RCBD) with eight treatments (cultivars) and three replications. Dimensions of the main plot were 51.5m length x 10.8m width giving a total area of 556.2m^2. The main plot was divided into 24 sub-plots spaced 0.5m apart and each measuring 6m × 3.6 m consisting of 5 rows that were 0.90m apart. Potato seeds were planted 0.70m between planting stations giving a population of 30 plants per plot and 240 plants for the whole experiment.

2.3 Agronomic practices:

The field was cultivated using tractor mounted plough digging in the soil to the depth of 25-30cm, after which the plots were leveled using disc harrow. Treatments were applied on the sub-plots according to trial plan. Medium sized and well sprouted tubers were planted on the sides of ridges which were dug using the spade. The planting depth was maintained at 0.25m. Wonder 2:3:2 [14] granular basal fertilizer was applied at the rate of 20kg per 556.2m^2. Fertilizer was placed inside the furrow, while the potato seed was placed on the side of the furrow to avoid direct contact between fertilizer and seeds. Later, both fertilizer and seed were covered with soil. Planting was performed by hand. Weeding was done four times due to high level of weed infestation. Cyperthrin 200 insecticide was applied against blister beetle (*Milabris oculata*) insect using the knap sack sprayer. Irrigation was performed using hose-pipe once in a week.

2.4 Data collection and analysis:

Data were collected using descriptor of potato (*Solamun tuberosum* L.) compiled by International Board of Genetic Resources Unit (1982) and revised by Kawochar and Mohammed (2015) [21]. Three plants in a plot were tagged where all the measurements were taken every time recording was performed. The characters of potato plants measured to distinguish cultivars based on plant parts were:

- Stem: number of main stems, stem dry weight, stem fresh weight, stem diameter, root fresh weight;
- Leaf: leaf dry weight, leaf fresh weight, number of leaves, leaf width, leaf length, leaflet length, leaflet width;
- Tuber: marketable tubers, tuber fresh weight, total yield, tuber fresh weight, large size tubers, chlorophyll content, unmarketable tubers, medium size tubers;
- Root: root dry weight.

Data collected were captured and entered into Microsoft Excel, after which data were analyzed using GENSTAT (version 17) software to generate cluster analysis and principal component analysis.

III. Results and Discussion

3.1 Cluster analysis:

Data generated from twenty-one traits were used to draw a cluster analysis (Dendrogram) (Fig. 1) below, which established genetic distance among eight potato cultivars. The cultivars used in this study were Panamera, Innovator, Valo, Tyson, Mondial, Taurus, Tyger and Avalanche.

Cluster analysis (Fig.2) consisted of one main group which was divided into two sub-groups, namely; 1 and 2. Sub-group 1 comprised sub-sub-group A which further sub-divided into A (i) which still further sub-divided into sub-sub-group A (iii) containing Innovator, A (iv) Avalanche and (v) Tyson, A(ii) contained Tyger. Sub-group B was an outlier. Sub-group 2 sub-divided into sub-sub group C and D. D became an outlier, whereas C further still divided into i and ii being Panamera and Taurus.

At a higher level of hierarchy, cluster analysis (Fig.1) showed a closer relationship among the cultivars, but as more and more traits were applied the cultivars separated into distinct groups, individuals and positioned as outliers. This implied that their genetic make-up differed greatly from each other. The outliers exhibited that they had many traits that separated them from others and make them stand alone. Conversely, those cultivars which clustered together at a very low level of hierarchy expressed high degree of similarity, thus most of the genes that they had were similar. The results of this study resonated with findings of some researchers who generated dendrogram using morphological traits of 42 potato germplasm collected from Ethiopia [23]. It grouped 42 potato cultivar into four main clusters, and reported high degree of similarity between two cultivars among Ethiopian nationally released cultivars. Similarly, a study was conducted on 30 potato cultivars, which were formed into six clusters [24]. The inter cluster distances were higher than the average intra cluster distances, which indicated wide genetic diversity among cultivars of different groups than those of the same cluster. Again, another study conducted it was revealed that 20 potato cultivars studied constructed clusters and had higher mean values for desirable traits [25]. It was further observed that the inter-cluster genetic distance was greater that the intra cluster for all clusters indicating that considerable amount of genetic diversity existed between cultivars of different groups.

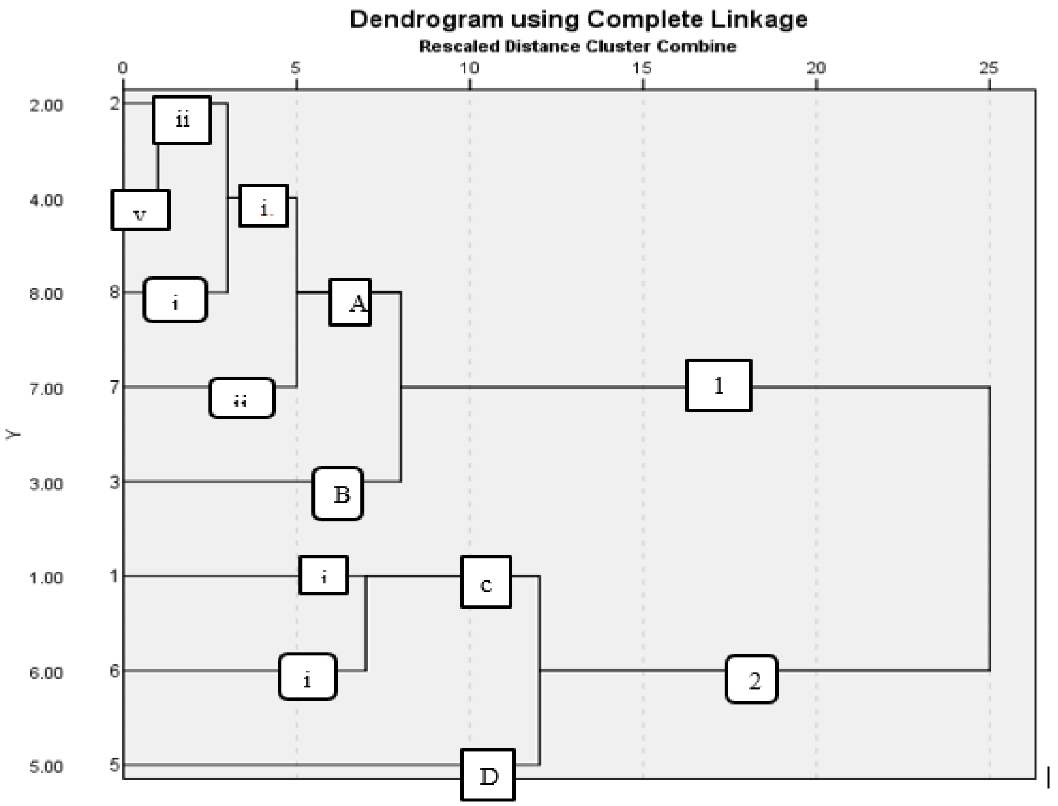

FIGURE 1: Dendrogram displaying genetic distance among potato cultivars; Panamera (1.00), Innovator (2.00), Valor (3.00), Tyson (4.00), Mondial (5.00), Taurus (6.00), Tyger (7.00), and Avalanche (8.00).

3.2 Principal Component Analysis:

Table 1 below depicts the contribution of each principal component towards the genetic variability in eight potato cultivars. Six principal components accounted for 97.490% of the total variation in distinguishing the potato cultivars. Principal Component 1, 2, 3, 4, 5, and 6 contributed 42%, 17%, 14%, 10%, 6% and 5%, respectively, implying that they were adequate to distinguish the eight potato cultivars in this study. Principal component analysis subjected 21 characters to distinguish potato cultivars and apply their discriminatory power among eight potato cultivars, after which they were ranked accordingly. Principal component 1 consisted of marketable tubers, root fresh weight, tuber fresh weight, number of main stems, leaf dry weight, leaf fresh weight, total yield, stem dry weight, stem fresh weight, large size tubers and leaf length. Principal component 2 comprised leaf width and stem diameter, while PC 3 consisted of unmarketable tubers, medium size tubers and leaflet length. Principal component 4 and PC 5 consisted of leaflet width and root dry weight, respectively as depicted on Table 2 below.

These traits had a high discriminating power that enabled the potato cultivars to be distinguished. Nonetheless, no single or two traits were able to distinguish any potato cultivars necessitating more than three characters to be applied in order to differentiate some but not all, hence the number of traits had to be increased in order to separate more cultivars. This is consistent with a study that assessed the total variation among 24 potato cultivar for 23 quantitative and six qualitative traits [25]. The first eight principal components accounted for 90.26% of the total genetic variation. The first eight components were retained in analysis because Eigen values were greater than 1. The other factors having Eigen values greater than 1 were ignored due to Gutten's lower bound principle. Furthermore, in the evaluation of diversity among potato cultivars using agro-morphological and yield components, it was observed that there was 80.1% of the total variation among traits [26]. The first PC comprised tuber yield, tuber weight, dry matter content and harvest index. They suggested that the principal component was very important for differentiating highly related clones and parents for breeding. Similarly, a study of principal component analysis of twelve potato cultivars was conducted, and only the two component axes had eigenvalues up to 1.0% representing cumulative variance of 84.1% and therefore suggested that the important traits considered effective in the investigation with respect to agronomic traits were yield per plant, number of tubers per plant, tuber weight per plant, plant height, plant emergence and leaves per plant [27].

TABLE 1
CONTRIBUTION OF EACH PRINCIPAL COMPONENT TO THE VARIATION IN THE POTATO CULTIVARS

Principal component	Initial Eigenvalues	Total % of variance	Cumulative %
1	9.448	42.943	42.943
2	3.752	17.056	59.999
3	3.13	14.228	74.227
4	2.315	10.525	84.752
5	6.828	6.828	91.579
6	1.3	5.91	97.49
7	0.552	2.51	100

TABLE 2
COMPONENT MATRIX

Parameters	Component				
	1	2	3	4	5
1. Marketable tubers	0.948				
2. Root fresh weight	0.927				
3. Tuber fresh weight	0.918				
4. Number of main stems		0.894			
5. Leaf dry weight	0.884				
6. Leaf fresh weight	0.88				
7. Total yield	0.87				
8. Stem dry weight	0.832				
9.Tuber fresh weight	0.795				
10. Stem fresh weight	0.767				
11. Large size tubers	0.712				
12. Leaf length	0.658				
13. Number of leaves	0.611				
14. Chlorophyll content			-0.872		
15. Leaf width		0.658			
16. Stem diameter		0.635			
17. Unmarketable tubers				-0.801	
18. Medium size tubers			0.716		
19 Leaflet length			0.68		
20. Leaflet width				0.736	
21. Root dry weight					0.675

3.3 Loadings (Rotated factors):

Table 3 below revealed six rotated factors. Regarding rotated factors, leaf fresh weight (0.942), total yield (0.935), tubers dry weight (0.924), total yield (0.935), tubers dry weight (0.924), tubers fresh weight (0.915), marketable tubers (0.901), large size (0.761), number of main stems (0.735), root fresh weight (0.711), leaf dry weight (0.697), number of leaves (0.655) all had high positive loadings on the first factor, and low loadings on the second, third, fourth and sixth. Stem fresh weight (0.905), leaf length (0.891), stem dry weight (0.834) and tuber medium size (0.756) had high positive loadings on the second factor and low positive loading on the first and fifth. The third and fourth had both negative and positive loadings except for the sixth which only had negative loading. Leaf width (0.903) and stem diameter (0.696) had high positive loading the third factor had low positive loading. The unmarketable tuber (0.885) and tuber small size (0.762) had high positive loading but leaflet length had negative (-0.835) loading on the fourth factor and positive loading on the first, second and fifth. Root dry weight (0.968) had high positive loading on the first, second and fifth factor but negative on third, fourth and sixth. Leaflet width (– 0.793) had high negative loading on the sixth factor and positive loading on the first, second and fifth except third and fourth where it had both negative and positive loadings.

TABLE 3
ROTATED MATRIX

Parameters	Components					
	1	2	3	4	5	6
Leaf fresh weight	0.942					
Total yield	0.935					
Tuber dry weight		0.924				
Tuber fresh weight	0.915					
Marketable tubers	0.901					
Large size tubers		0.761				
Number of main stems	0.735					
Root fresh weight		0.711				
Leaf dry weight		0.697				
Number of leaves		0.655				
Stem fresh weight		0.905				
Leaf length		0.891				
Stem dry weight		0.834				
Medium size tubers		0.756				
Leaf width			0.903			
Chlorophyll content			-0.864			
Stem diameter			0.696			
Unmarketable tubers			0.885			
Leaflet length				-0.835		
Small size tubers				0.762		
Root dry weight						0.968
Leaflet width						-0.793

IV. CONCLUSIONS

The results revealed that there was a wide variation among eight potato cultivars which can be exploited in the breeding. The variation existed in vegetative, reproductive, seed and physiological maturity features. Cultivars can be tested under varying environmental conditions to screen for the most suitable for specific localities. Mondial showed to be the only cultivar with large tuber size, followed by Panamera and Taurus, respectively. Characters with high discriminatory power were marketable tubers, root fresh weight, tuber fresh weight, number of main stems, leaf dry weight, leaf fresh weight, total yield and stem dry weight.

DATA AVAILABILITY STATEMENT

Data will be shared upon request.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

NUL: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review and editing.

DECLARATION OF COMPETING INTEREST

The authors of this manuscript declare that there is no conflict of interest or competing interest.

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Eco-Friendly Alternatives for Managing Plant Diseases: Lessons from *Ageratum conyzoides* -A Review

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Abstract— *Ageratum conyzoides, commonly known as billygoat weed or goatweed, poses a significant threat to agricultural ecosystems, negatively impacting crop productivity and biodiversity. Due to environmental concerns associated with conventional control methods, this comprehensive review critically examines the current state of biological control strategies for A. conyzoides. The study explores three major categories of biological control agents: insects such as the Ageratum gall fly (Procecidochares utilis) and the Ageratum stem-boring weevil (Listronotus setosipennis), which disrupt weed growth through gall induction and stem boring, respectively; fungal pathogens that induce diseases compromising weed vigor; and herbivorous livestock, particularly controlled grazing by goats and sheep, as a natural means of suppression. The review evaluates the efficacy of these agents while considering key environmental factors such as climate and soil characteristics. Special emphasis is placed on minimizing non-target effects through host specificity assessments and optimizing biocontrol implementation strategies. Additionally, challenges including the potential development of resistance in A. conyzoides, the necessity of integrating multiple control measures, and existing knowledge gaps are discussed. This study underscores the importance of continued research and the adoption of integrated pest management (IPM) approaches to achieve sustainable and ecologically sound weed control. In conclusion, this review provides valuable insights into eco-friendly weed management practices, contributing to sustainable agricultural production and biodiversity conservation*.

Keywords— Ageratum conyzoides, biological control, weed management, insect pests, pathogens, sustainable agriculture, environmental conservation.

I. INTRODUCTION

Agriculture, a cornerstone of human civilization, continually confronts challenges from various pests and invasive species that threaten the productivity of cultivated lands and the equilibrium of ecosystems. **A. conyzoides**, colloquially known as **billygoat weed** or **goatweed**, has emerged as a formidable adversary in this intricate dance between human cultivation and the natural world. Native to tropical and subtropical regions, this tenacious weed possesses a remarkable ability to adapt and proliferate, casting its shadow over crops, pastures, and natural habitats

As the global agricultural landscape grapples with the impact of conventional herbicides on the environment and concerns about their sustainability, the exploration of alternative and eco-friendly control strategies becomes imperative. Singh, M. (2024). **Biological control**, a time-honored approach, harnesses the inherent mechanisms of the natural world to manage pest populations. In the context of *A. conyzoides*, a weed with a pervasive presence, the quest for effective biological control agents has gained momentum, driven by the need for sustainable solutions that harmonize with the delicate balance of ecosystems.

II. LITERATURE REVIEW

This literature review explores a selection of studies that investigate the antifungal, pesticidal, and allelopathic properties of *A. conyzoides* and its potential applications in sustainable agriculture.

2.1 Antifungal Activity:

The study by Javed and Bashir (2012) investigates the antifungal activity of different extracts of *A. conyzoides* against *Fusarium solani*. Published in the *African Journal of Biotechnology*, the research explores the potential of *A. conyzoides* as a natural agent for managing fungal pathogens, shedding light on its bioactive compounds.

Building upon this, Iqbal et al. (2004) contribute to the understanding of *A. conyzoides* fungistatic properties. Their work, published in *Phytoparasitica*, identifies a fungistatic chromene from *A. conyzoides*, showcasing the richness of bioactive compounds within the plant that may contribute to its antifungal properties.

In a more recent study, Banaras et al. (2021) perform bioassays-guided fractionation of *A. conyzoides* extract to identify natural antifungal compounds against *Macrophomina phaseolina*. Published in the *International Journal of Agriculture and Biology*, this research highlights the potential of *A. conyzoides* in biocontrol against specific fungal pathogens.

Ndacnou et al. (2020) contribute to the phytochemical study of *A. conyzoides* and assess its anti-oomycete activity. Published in *Industrial Crops and Products*, their work expands our understanding of the plant's chemical composition and its relevance in managing oomycete infections.

2.2 Pest and Disease Management

Rioba and Stevenson (2017) explore the utilization of *A. conyzoides* for the management of pests and diseases by smallholder farmers. Published in *Industrial Crops and Products*, this study provides insights into the practical applications of *A. conyzoides* in real-world agricultural settings.

Chen et al. (2023) contribute to the field by screening and characterizing biocontrol bacteria isolated from *A. conyzoides* against *Colletotrichum fructicola*, a pathogen causing Chinese plum anthracnose. Their work, published in *Frontiers in Microbiology*, showcases the potential of *A. conyzoides* not only as a direct biocontrol agent but also as a source of beneficial microbes for integrated pest management.

2.3 Allelopathic Potential:

Kong et al. (1999) and Kong et al. (2004) delve into the allelopathic potential of *A. conyzoides*. The studies, published in the *Journal of Chemical Ecology* and *Allelopathy Journal*, respectively, explore the plant's ability to release allelopathic compounds that inhibit the growth of neighboring plants. This allelopathic potential holds promise for weed management in agroecosystems.

2.4 Multi-faceted Contributions:

A comprehensive study by Chahal et al. (2021) examines *A. conyzoides* and its secondary metabolites in the management of different fungal pathogens. Published in *Molecules*, this research not only highlights its antifungal properties but also emphasizes the plant's potential against a spectrum of fungal adversaries.

2.5 Beyond Agriculture:

A. conyzoides is not limited to agricultural applications alone. Paul et al. (2022) discuss its potential in turning waste into beneficial resources, implying implications in sustainable agriculture, the environment, and the biopharma sectors. Published in *Molecular Biotechnology*, this study broadens the scope of *A. conyzoides*' contributions.

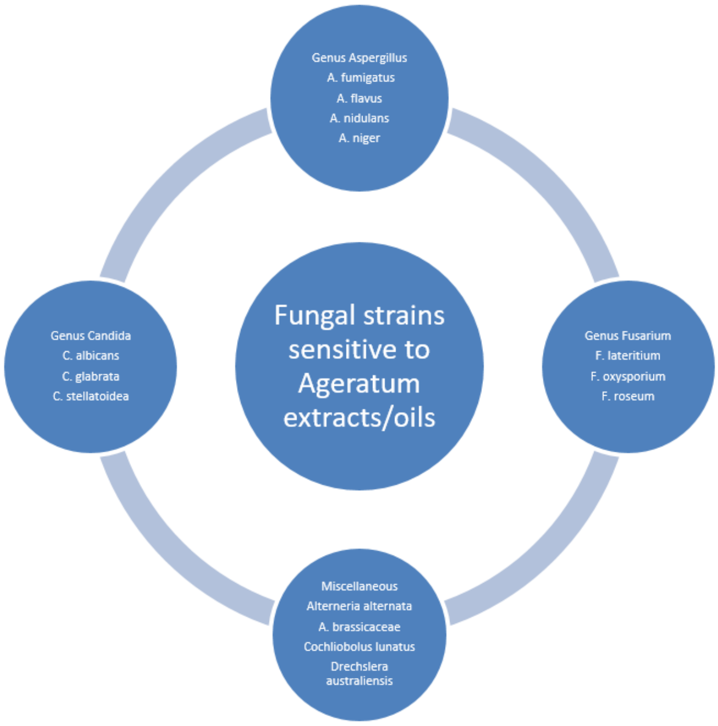

FIGURE 1: Fungal strains sensitive to *Ageratum* extracts/oils

III. AGERATUM CONYZOIDES

A. conyzoides, a member of the **Asteraceae** family, stands as a testament to nature's resilience and adaptability. Exhibiting a penchant for disturbed habitats, agricultural fields, and open spaces, this annual herbaceous plant has earned its reputation as a noxious weed. Its rapid growth, prolific seed production, and allelopathic properties contribute to its ability to outcompete native vegetation, compromising biodiversity and impacting crop yields. The invasiveness of *A. conyzoides* poses a significant threat to both agricultural productivity and the ecological integrity of diverse landscapes. Kumar, R et al, (2024).

Traditional methods of weed control, often reliant on chemical herbicides, come with a litany of concerns. Environmental contamination, the development of herbicide-resistant strains, and unintended harm to non-target organisms raise questions about the sustainability of these practices. Consequently, the imperative to explore alternative, environmentally benign strategies for *A. conyzoides* management has driven researchers, agriculturalists, and environmentalists towards the realm of biological control. Kumar, R et al, (2022).

IV. BIOLOGICAL CONTROL

Biological control, a branch of **integrated pest management (IPM)**, harnesses the natural enemies of pests to limit their populations and mitigate their impact. In the case of *A. conyzoides*, biological control represents a promising avenue for sustainable weed management. By leveraging the interactions between organisms within ecosystems, this approach aims to restore a semblance of balance, allowing native flora to thrive while suppressing the invasive billygoat weed. Chen, S et al, (2025).

The concept of biological control extends across various trophic levels, involving predators, parasitoids, pathogens, and herbivores. In the intricate dance of nature, certain organisms have evolved to exploit specific vulnerabilities of *A. conyzoides*, be it through feeding, parasitism, or inducing diseases. The focus on biological control aligns with broader trends in sustainable agriculture, emphasizing the need for holistic and environmentally friendly solutions.

V. INSECTS AS BIOLOGICAL CONTROL AGENTS

In the arsenal of biological control agents, insects emerge as key players in the endeavor to manage *A. conyzoides*. The **Ageratum gall fly (Procecidochares utilis)** and the **Ageratum stem-boring weevil (Listronotus setosipennis)** showcase the potential of insects to disrupt the weed's life cycle. The gall fly's intricate dance involves laying eggs on *A. conyzoides*, inducing gall formation that disrupts the weed's growth and reproduction. Simultaneously, the stem-boring weevil's larvae burrow into the stems, causing structural damage and reducing the vigor of the billygoat weed. Kato-Noguchi and Kato, (2024).

These insects, acting as natural adversaries, exemplify the elegance of coevolution and the intricate mechanisms through which the natural world seeks equilibrium. The specificity of these insects to *A. conyzoides* minimizes the risk to non-target species, aligning with the principles of precision and sustainability inherent in biological control.

VI. PATHOGENS

Fungal pathogens, another cohort of biological control agents, introduce a different dimension to the battle against *A. conyzoides*. Certain fungi exhibit an aptitude for infecting the weed, causing diseases that compromise its growth and reproductive potential. This silent warfare beneath the soil surface not only weakens the individual plants but also curtails the spread of *A. conyzoides* by affecting its seed production.

The use of fungi as biocontrol agents is notable for its potential specificity to the target weed, minimizing the risk to non-target species. This approach aligns with the ecological principles of sustainability, offering a focused solution to the challenges posed by *A. conyzoides* in diverse ecosystems.

VII. LIVESTOCK GRAZING

Beyond the microscopic realm of insects and fungi, the integration of livestock, such as goats and sheep, introduces a macroscopic yet equally natural approach to *A. conyzoides* management. Grazing animals, with their voracious appetites for certain weeds, including *A. conyzoides*, offer a sustainable and economically viable solution. Controlled grazing not only reduces the biomass of billygoat weed but also contributes to nutrient cycling and promotes a diverse and resilient pasture ecosystem.

The use of livestock as biological control agents aligns with the principles of **agroecology**, where agriculture is viewed through an ecological lens, recognizing the interconnectedness of various components within the system. As these animals graze, they act as stewards of the land, participating in a natural symphony that echoes the principles of sustainable land management.

TABLE 1
ANTIFUNGAL ACTIVITIES OF MAIN CONSTITUENTS EXTRACTED FROM AGERATUM CONYZOIDES

Constituent	Antifungal Activity Against	Target Pathogen
Chromene	Fusarium solani	Fusarium solani
	Macrophomina phaseolina	Macrophomina phaseolina
Bioactive Compounds	Lasiodiplodia theobromae	Lasiodiplodia theobromae
	Lasiodiplodia pseudotheobromae	Lasiodiplodia pseudotheobromae
Essential Oil	Aspergillus spp.	Virulent Aspergillus spp.
	Phytophthora capsici	Phytophthora capsici
Allelochemicals	Various fungal pathogens	Various fungal pathogens

VIII. CHALLENGES AND OPPORTUNITIES IN BIOLOGICAL CONTROL

While biological control holds immense promise in managing *A. conyzoides*, it is not without its challenges. The potential for the weed to develop resistance to biocontrol agents, concerns about unintended harm to non-target species, and the need for a nuanced understanding of the ecological dynamics within specific ecosystems are pivotal considerations. Addressing these challenges requires a multidisciplinary approach, blending ecological insights with advancements in entomology, plant pathology, and agronomy.

The integration of biological control into a broader weed management strategy becomes paramount in navigating these challenges. Recognizing that no single solution fits all scenarios, an approach that combines biological control with cultural, mechanical, and chemical methods, under the umbrella of integrated pest management (IPM), emerges as a comprehensive strategy. Li, Y et al, (2025).

IX. CONCLUSIONS

The management of *Ageratum conyzoides* remains a critical challenge in sustainable agriculture, necessitating an integrative approach to mitigate its adverse effects on crop production and ecosystem stability. This review comprehensively elucidates the role of biocontrol strategies, including insect-mediated suppression, fungal antagonism, and livestock grazing, in effectively reducing the competitive dominance of this invasive weed. The utilization of *Procecidochares utilis* (*Ageratum* gall fly) and

Listronotus setosipennis (*Ageratum* stem-boring weevil) demonstrates species-specific interactions that disrupt weed physiology, thereby limiting growth and reproductive potential. Concurrently, pathogenic fungi exert significant mycoherbicidal effects, causing structural degradation in plant tissues, ultimately leading to suppression of *A. conyzoides* populations. The allelopathic properties of *A. conyzoides*, attributed to bioactive secondary metabolites such as chromenes, flavonoids, and terpenoids, present both an ecological advantage and an agricultural constraint. While these compounds exhibit antifungal and insecticidal properties, their persistence in the soil matrix can influence native flora and soil microbiota, necessitating further investigation into their long-term ecological implications. Livestock grazing, particularly by goats and sheep, provides an ecologically sustainable weed suppression method, contributing to nutrient cycling and enhancing soil organic matter content. However, variable palatability and grazing preferences among livestock species require optimized grazing protocols to maximize efficacy. Integration of these biocontrol strategies within the framework of integrated weed management (IWM) offers a multifaceted approach to managing *A. conyzoides*. Synergistic combinations of biological, cultural, and chemical control methods, guided by ecological principles, can enhance long-term suppression while mitigating resistance development. Nevertheless, biocontrol implementation is constrained by environmental heterogeneity, host specificity of agents, and regulatory challenges in field application. Future research should emphasize molecular characterization of plant-microbe interactions, genomic insights into resistance mechanisms, and formulation of biopesticides derived from *A. conyzoides* extracts for targeted weed suppression. This review underscores the significance of biocontrol as an environmentally benign alternative to conventional herbicide-based weed management. Advancements in microbial consortia, gene-editing technologies for pest resistance, and precision agriculture tools hold promise for refining biocontrol efficacy. The holistic adoption of sustainable weed management strategies will ensure ecological balance, enhance crop resilience, and contribute to long-term agricultural productivity.

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Effect of Sowing Time,Planting Geometry and Topping on Seed Yield of Roselle (*Hibiscus sabdariffa L.*) in East and South Eastern Coastal Plain Zone of Odisha

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Abstract—*To optimize sowing time, spacing and topping schedule for quality mesta seed production, an experiment with three dates of sowing [21st May (D_1), 5th June (D_2) and 21st June (D_3)], three spacing treatments [30 x 10 cm (S_1), 45 x 10 cm (S_2) and 60 x 10 cm (S_3)] and two topping schedules [30 DAS (T_1) and 45 DAS (T_2)] were laid out in split-split-plot arrangements with three replications. Different yield attributing characters and seed yield of roselle was significantly influenced by date of sowing and spacing arrangements.*

It was observed that sowing dates influenced different growth parameters as well as yield significantly. D_2 sown crop recorded maximum seed yield (6.4q ha^{-1}) and statistically at par with D3 (6.17q ha^{-1}).Similarly spacing arrangements also had a significant impact seed yield of roselle, with highest seed yield of 6.4q ha^{-1} obtained under 45×10 cm spacing followed by 60×10 cm spacing (6.28q ha^{-1}).Topping done at 45 DAS resulted in 5.3% higher yield than that of 30 DAS. Yield attributing characters were not significantly influenced by topping schedules. Maximum net return of above Rs 27,000/ha was obtained, when the crop was sown on 5th June, with 45cmX10cm spacing and topping scheduled on 45 DAS with a B:C ratio of 1.76.Hence, it can be suggested that, sowing of mesta (roselle) during 1st week of June to third week of June with 45 x 10 cm and topping at 45 DAS should be recommended to harvest maximum quantity seeds in east and south eastern coastal plain zone of Odisha.

Keywords— Roselle, topping, seed yield, sowing time, spacing.

I. INTRODUCTION

Roselle *(Hibiscus sabdariffa L.),* a herbaceous, annual lignocellulosic bast fibre crop is successfully grown as a commercial crop in coastal regions of Odisha. Roselle (Hibiscus sabdariffa L.) is a plant that has medicinal properties backed by scientific studies; however, it is also used to dye food, soft drinks, syrups, among other products (Gardezi *et al*, 2020). It finds its place next to jute in importance. Although it's tougher and coarser than jute fibre, however, equals in quality to the medium grades of jute (Berger, 1969). It is the nearest ally of jute and plays an effective role in supplementing the short supply of jute industry. Mesta fibre is blended with jute fibre and used for making of cordage, rope, twines, hessian, sacking and geotextile etc [Da-CostaRocha et al., 2014]. The fibre content and other chemical properties make it a commercial crop next to jute and cotton [Kumar et al,2020]. Apart from fibre production, diversification of roselle for paper pulp production finds its importance with the growing domestic and global demand for paper pulp. Apart from fibre and pulp, its seeds also contain 18-20% oil which can be directly used in soap and other industries. Hence, seed production in this crop, during recent years is also gaining popularity. Besides, there is also an imbalance between total seed requirement for fibre production and total available seed, reflecting a steep increase in price of seeds imported from other states. Literatures are available regarding optimization of agro-techniques for maximizing the fibre production in roselle. However, reports related to improved method including suitable time of sowing with specific planting geometry, for increasing the seed production in roselle is very meager. Reports are also available on importance of topping practice in increasing the yield levels in different crops (Singh *et al*., 2013). Besides, significance of weeding frequency and fertilizer levels on dry seed weight, fresh and dry weight of calyx yield of roselle plants were also studied (Bake,2015). Keeping all these factors in consideration, a two year field experiment was conducted during the *Kharif* season of 2018 and 2019 with the objective to study and assess the optimum date of sowing, planting geometry and topping schedule for higher seed production in *roselle (H.sabdariffa L).*

II. MATERIALS AND METHOD

The experiment was conducted during *kharif* seasons in 2018 and 2019 at Jute Research Station, Kendrapara (19^0 34' N latitude and 86^0 30' E longitudes). The soil of the experimental field was sandy loam with pH 6.5,organic carbon 6.2g/kg and available N,P and K 297,28.2 and 255kg/ha, respectively. The experiment was a randomized complete block design with split-split-plot arrangements and three replications. Date of sowing (D_1- 21st May, D_2- 5th June and D_3- 21st June) was assigned to the main plots, spacing (S_1- 30 x 10 cm, S_2- 45 x 10cm and S_3- 60 x 10 cm) assigned to the sub-plots and topping (T_1- 30 DAS and T_2- 45 DAS) was assigned to the sub-sub-plots having total 18 treatment combinations. *H.sabdariffa* variety (*Roselle*), AMV *5* was sown on the above dates under three different spacing arrangements. The uniform fertilizer dose given to each and every plot was N, P_2O_5 and K_2O @ 60:30:30 kg ha^{-1}. For data collection on growth and other yield attributing characters five plants were picked at random from each plot. At maturity, all plants from each net plot were harvested. Plants were threshed and seeds were separated, sundried, cleaned and weighed. Seed yield per hectare was worked out and expressed in quintal ha^{-1}. While calculating gross return prevalent market price for sale of *Roselle* seed was taken as Rs. 100**.**00 kg^{-1}.

III. RESULTS AND DISCUSSION

Perusal of data revealed that, seed yield of mesta was significantly influenced by dates of sowing, spacing and topping schedule. Crop sown on 5th June recorded significantly higher seed yield of 6.4q/ha as compared to the remaining two dates of sowing (Table 1). This may be attributed to better growth of the plant in terms of number of productive branches per plant (6.8), pods per plant (33.86) and number of seeds/pod (26.47) when sown on this date. The results obtained confirm the findings of Venkatakrishnan et al. (2004).Seed yield of mesta was enhanced under wider spacing and maximum seed yield of 6.44q ha^{-1} was obtained under 45cmX10cm spacing and it remained statistically at par with 60cmX10 cm spacing(6.28q ha^{-1}).

Though widest spacing (60cm×10cm) performed better, when the growth parameters viz. productive branch per plant,pods per plant and seeds per pod were taken into consideration. However, yield could not increase up to the highest extent due to less plant population per unit area.

Topping of apical buds induced the growth of auxiliary branches and had a positive impact on other yield attributing parameters on both 30 and 45 DAS. Topping done on 45DAS resulted 5.3% more seed yield (6.3q ha^{-1}) than that on 30 DAS (6 q ha^{-1}). However, the number of seeds per pod and test weight did not vary significantly due to topping treatments. Similar findings were reported for white jute seed production (Patra *et al*,2017).He found sowing on 5th June along with topping done on 45 DAS, resulted in maximum net return of Rs.27689.00 and B:C ratio of 1.76. The interaction effect for of all the yield attributing characters remained non-significant.

Maximum net return of above Rs 27,000/ha was obtained, when the crop was sown on 5th June, with 45cmX10cm spacing and topping scheduled on 45 DAS with a B:C ratio of 1.76.

TABLE 1
EFFECT OF DATE OF SOWING, SPACING AND TOPPING ON GROWTH AND YIELD ATTRIBUTES OF ROSELLE (MEAN OF TWO YEARS)

Treatment	Productive br./plant	Pods /Plant	No. of Seeds/Pod	1000 seed weight(g)	Seed yield(q/ha)	Net return(Rs/ha)	B:C ratio
Date of sowing							
21st May(D_1)	5.2	29.7	25.2	22.4	6	23584	1.64
5th June(D_2)	6.8	31.3	26.4	22.5	6.42	27689	1.76
21st June(D_3)	5.8	31.9	26	22.26	6.17	25228	1.69
CD(0.05)	0.58	1.46	0.91	NS	0.067	661	0.021
Spacing							
30cm×10cm(S_1)	5.5	26.6	25.2	22.26	5.87	22228	1.61
45cm×10cm(S_2)	6.4	33.8	26.4	22.5	6.44	27920	1.76
60cm×10cm(S_3)	6	32.6	26	22.4	6.28	26364	1.73
CD(0.05)	0.35	0.72	0.85	NS	0.037	366	0.011
Topping							
30DAS(T_1)	6	30.8	25.7	22.4	6.039	23890	1.65
45DAS(T_2)	5.98	31.2	26	22.37	6.362	27116	1.74
CD(0.05)	NS	NS	NS	NS	0.08	812	0.023
Interactions							
DXS							
SE m(±)	0.195	0.406	0.482	0.121	0.021	205.9	0.006
CD(0.05)	NS	1.2	NS	NS	0.063	634	0.018
DXT							
SE m(±)	0.192	0.34	0.273	0.065	0.047	473.3	0.014
CD(0.05)	NS	NS	NS	NS	0.141	1406	0.04
SXT							
SE m(±)	0.192	0.34	0.273	0.065	0.047	473.3	0.014
CD(0.05)	NS	NS	NS	NS	NS	NS	NS
DXSXT							
SE m(±)	0.333	0.58	0.473	0.113	0.082	812.7	0.023
CD(0.05)	NS	NS	NS	NS	NS	NS	NS

IV. CONCLUSION

Based on the present study, it can be concluded that sowing of mesta (roselle) crop during first week of June with 45 x 10 cm spacing and scheduling one topping at 45DAS can be recommended to increase the seed production of mesta in eastern and south eastern coastal plain zone of Odisha.

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Environmental Footprint of Dairy-Based Agriculture: Indicator-Based Assessment and Mitigation Approaches

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Abstract— *Environmental sustainability is a key component of resilient agricultural systems, particularly in integrated dairy-based farming where livestock interacts closely with the ecosystem. This study assesses environmental sustainability through nine indicators: animal health, housing conditions, calf raising, use of dung, water management, drought preparedness, disposal of packaging, urine management, and animal carcass disposal. Based on responses from 100 dairy farmers, findings show that while indicators such as animal health and dung use scored high, weaknesses were noted in drought preparedness, water management, and waste disposal. The Environmental Sustainability Index (EnSI) for the farms ranged from 0.22 to 0.84, with the majority categorized as moderately sustainable. These results underline the importance of targeted interventions to enhance sustainability in dairy-based systems.*

Keywords— Environmental sustainability, Indicators, Dairy farming, Kumaon, Uttarakhand.

I. INTRODUCTION

Human beings have long had an inherent tendency to conserve resources for future generations. This instinct has helped sustain nature and natural resources since prehistoric times. However, in the past two centuries, the Earth's ecosystem has faced unprecedented pressure due to rapid population growth, industrialization, and urbanization. The sudden rise in population in certain regions, combined with expanding urban settlements and industrial activities, has triggered significant strain on natural resources. This situation compels us to critically examine whether our current model of development truly leads us toward progress—or whether it misguides us away from sustainability. Sustainability refers to the responsible and balanced use of resources in a manner that meets present needs without compromising the ability of future generations to meet theirs. It is commonly conceptualized through three interdependent pillars: economic**,** social**,** and environmental sustainability. While the debate continues over which pillar is most critical, it is now widely acknowledged that over-exploitation of natural resources today will make life more difficult for future generations. Dairy farm sustainability issues are often categorized as either economic, environmental or social (von Keyserlingk et al., 2013) However, how to precisely define, how to measure, and how to operationalize sustainable development in various societal domains remain a work in progress within the scientific community (Gibbes et al., 2020; Ruggerio, 2021). In simpler terms, sustainability represents an informal contract between the current and future generations, ensuring that resources are preserved in their current form and availability for continued use.

India became the most populous country in the world in 2023, and its population is projected to grow further at least until 2050. Simultaneously, India is undergoing rapid urbanization. Projections indicate that by 2046, more than half of its population will live in urban areas. This demographic shift will significantly intensify the demand for limited resources, particularly food, water, and energy. The present moment is critical to reflect on whether our development trajectory aligns with the principles of sustainability. According to the United Nations, global food demand is expected to double by 2050, driven by a rising population—from 7.6 billion in 2017 to 8.6 billion by 2030, 9.8 billion by 2050, and more than 11.2 billion by 2100.

In front of tremendous changes in world population, arable land availability and all global climate activities must be directed to increase the overall food production by almost 70 % by 2050, corresponding to an annual increase of 1.75 % in productivity to meet the future demand (Global Harvest Initiative. 2010). Only by following the principles of sustainability (Devendra, 2001) the most countries have a realistic chance to reach by 2050 the goal to produce demand related quantities of food.

Agricultural systems worldwide must respond to this surge in demand by increasing food production—while doing so in ways that are nutritious, healthy, and environmentally sustainable. The dairy sector, in particular, faces both opportunities and challenges in this regard. Dairy farming has historically been an integral part of human civilization, deeply embedded in social, cultural, and economic systems across the globe. Today, the growing emphasis on food and nutrition security has further increased the importance of dairy products. Milk and its derivatives are now essential dietary staples, found in nearly every household and kitchen. Dairy farming has rapidly intensified over the past 50 years (FAO 2018a). Current modes of dairy intensification are widely recognized to generate negative impacts along multiple dimensions: the environment (Del Prado et al. 2013), animal welfare (Koeck et al. 2014), human health (Westhoek et al. 2014), and rural livelihoods and well-being (Flaten 2002). Sustainable intensification, in brief, denotes an aim of increasing productivity while simultaneously decreasing the negative environmental effects of conventional farming practices (Garnett et al. 2013).

India, as the world's largest milk producer, contributes approximately 25% of global milk production. Meeting future demands, given India's growing population and consumption, will require a significant transformation of dairy practices. While dairy farming is well-integrated into rural livelihoods and contributes substantially to the national economy, its environmental consequences remain underappreciated.

The sustainability of dairy production systems is being undermined by several environmental challenges. These include greenhouse gas (GHG) emissions, water usage and contamination, and land degradation. As Hossain et al. (2025) note, such impacts threaten long-term ecological stability, while Basaragi and Kadam (2024) suggest that climate-smart practices and value-added dairy products offer potential pathways to sustainability. To preserve this fragile ecosystem, instead, there is a need to develop a dairy farming system which must be sustainable for the animal and the environment and economically feasible (Cozzi and Bizzotto, 2004). In 2015, global milk production reached 666.5 billion kilograms, an increase of 30% from 2005 levels. This increase led to an 18% rise in GHG emissions, primarily due to methane (CH_4), nitrous oxide (N_2O), and carbon dioxide (CO_2) emissions (FAO, 2019). The marked changes in our environment (e.g., climate, soil degradation, water quality and availability, deforestation, greenhouse gas emissions, waste quantity, biodiversity) indicate that conventional farming, at least to some extent, should be changed to sustainable production systems (Hamann, 2017). Dairy farming is also one of the most water-intensive food industries, contributing significantly to water pollution. Meena (2018) highlights the dairy industry's role in emitting harmful gases and degrading water quality. Furthermore, research by de Vries and de Boer (2010), and Milani et al. (2011) indicates that livestock production—including feed cultivation, transport, processing, and consumption—has a disproportionately large impact on climate change.

The environmental sustainability of dairy practices varies significantly across regions. A study by Singh et al. (2024) found that milk production in Punjab is more environmentally efficient than in Rajasthan. The study highlights cattle feed as a major contributor to environmental impacts, along with the choice of packaging materials used for processed milk. Achieving synergy between economic viability and ecological sustainability represents a fundamental challenge and opportunity for the dairy industry (Britt et al., 2018).

Dairy cattle, in particular, affect the environment through their emissions and waste products. According to Naranjo et al. (2020), these impacts extend across air, water, and land systems. The Central Pollution Control Board (CPCB, 2020) reports that a single bovine animal weighing around 400 kg produces approximately 15–20 kg of dung and 15–20 liters of urine per day—contributing to substantial environmental burdens when scaled across herds. It is also observed that only very few studies in India have addressed the environmental aspects of milk production, out of which one published study is from Anand Gujrat for the accounting carbon footprint of milk production by small farmers (Garg et al., 2016). Milk is a staple food, and its environmental impact study can guide the policymakers to devise eco-efficient policy for sustainable growth. Assessing the sustainability of milk production in India (the largest milk producer country in the world) is essential to ensure that the dairy industry can meet the growing demands for dairy products while minimizing its negative impact on the environment, society, and the well-being of the people involved in the sector (Singh et al. 2024). The sustainability indicators are composed of different indicators, such as: environmental (air quality, water quality, energy consumption), social (quality of life, well-being, income distribution), and economic (consumption and production pattern, liquidity), and can act jointly, forming indexes, or separately, in the three spheres that comprise sustainability (Goswami et al., 2017, Rawlikowska et al.,2019 and Mandart et al.,2019). Sustainability is a concept and cannot be measured directly. Appropriate indicators must be selected to determine levels and duration of sustainability (Zinck and Farshad, 1995). To address sustainability challenges in agriculture, private and multi-stakeholder initiatives increasingly use sustainability indicators to monitor the sustainability impact of farms. These indicators can be part of standards for certification or assessment tools to measure farm performance. While these initiatives play an important role in navigating the sustainability transition, insight in how these governance initiatives operationalize sustainability in crop farming is lacking (Konefal et al., 2023)

In light of the environmental sustainability challenges associated with dairy farming, the present study was undertaken in the hilly state of Uttarakhand, India. The objectives of the study are:

1. To identify key environmental sustainability indicators relevant to dairy farming.
2. To assess these sustainability indicators in the context of hill farming systems.
3. To propose practical strategies and approaches for enhancing the environmental sustainability of dairy farming.

II. RESEARCH METHODOLOGY

The present study was conducted to during the year 2024-25 in Kumaon region of Uttarakhand covering two districts viz Alomra and Pithoragarh selected randomly. Fifty dairy farmers from five randomly selected villages (Ten from each selected village) were interviewed directly with a pre-tested scientific questionnaire to collect information and draw inferences from a total sample size of hundred dairy farmers. The data collected was compiled, tabulated, analyzed and interpreted with statistical means and comparison.

III. RESULT AND DISCUSSION

3.1 Environmental Sustainability:

Environmental sustainability of dairy farms was examined by considering the indicators i.e. Animal health, Housing conditions, calf raising condition, water management, preparedness to drought, Disposal of generated waste, urine, dung and dead animals disposal pattern which provide uncertainty and impose new constraints on product.

3.2 Environmental Sustainability Indicators:

Indicators are a subset of the many possible attributes that could be used to quantify the condition of a particular landscape, catchment or ecosystem (Walker 1998). In the present study following indicators were studied to draw environmental sustainability index.

3.2.1 Animal Health:

Animal health is the basis of sustainable dairy farming practices. Sound health of reared animals not only makes dairy an economical venture but also contribute to sustainability of the business. Data presented in Table 1 reveals that majority of dairy farmers (76.00 percent) were taking care of animal health whereas only 24.00 percent dairy farmers were having casual approach towards animal health. Many researchers has highlighted the importance of animal health in sustainability. Animal health plays a vital role in sustainable livestock farming balancing three components-environmental responsibility, economic viability, and social acceptability (Capper, 2012, Kenyon et al. 2013). A fall in disease levels of 10 percentage points is associated with an 800 million tonne decrease in greenhouse gas (GHG) emissions (Oxford Analytica., 2021)

3.2.2 Housing condition:

Proper housing which is conducive to good health, comfort and protection from inclement weather and which would enable the animals to utilize their genetic ability and feed for optimal production (TNAU, 2025). A data regarding housing condition of the animals is presented in Table 1. Distribution of respondents based on measure to check toxicity which reveals that most of the farmers (75.00 percent) were providing satisfactory housing conditions to their animals whereas 25.00 percent farmers were keeping their animals in open and kachha floors. An explanation towards this phenomenon might be higher exposure of SHG members to dairy farming trainings, media exposure and extension contacts.

3.2.3 Calf raising conditions:

Improving health and welfare outcomes for replacement and surplus dairy calves is important for the sustainability of the dairy industry. Table 19 reveals that majority of dairy farmers (75.00 percent) are taking care of calf raising conditions and providing necessary vaccinations to calves whereas only 15.00 percent dairy farmers were having casual approach in this regard.

3.2.4 Use of dung as manure over fuel:

Cow dung is a very serious problem for people around the farm. The problem is often caused by cow dung which is not handled professionally (Ratminingsih and Jumadi, 2020). India's soils are getting depleted of organic matter. If application of organic manure and such other sources to soil is not increased, the country will face serious sustainability challenges (NITI Aayog, 2023). Dung is created in dairy farming and its purposeful and sustainable use help in environmental stability. Study data presented in Table 1 reveals that 95 percent of the farmers were using dung as manure rather than direct fuel 5 percent.

TABLE 1
ENVIRONMENTAL SUSTAINABILITY INDICATORS FOR DAIRY FARMS

Respondents (n=100)	Category	
Animal health management	Not-Satisfactory (0-3)	Satisfactory (>3)
	24 **(44.00)**	76 **(56.00)**
Housing conditions of animals	Not-Satisfactory **(0-3)**	Satisfactory **(>3)**
	25 **(25.00)**	75 **(75.00)**
Calf raising conditions	Vaccinated **(0)**	Not Vaccinated **(1)**
	85 **(85.00)**	15 **(15.00)**
Use of dung as manure over fuel	Dung as fuel **(0)**	Dung as manure **(1)**
	5 **(05.00)**	95 **(95.00)**
Water Management	Not-Satisfactory **(0)**	Satisfactory **(1)**
	62 **(62.00)**	38 **(38.00)**
Preparedness to drought	Not-Satisfactory **(0)**	Satisfactory **(1)**
	82 **(82.00)**	18 **(18.00**
Disposal of medicine and feed packaging	Not-Satisfactory **(0)**	Satisfactory **(1)**
	60 **(60.00)**	40 **(40.00)**
Animal urine disposal	Not-Satisfactory **(0)**	Satisfactory **(1)**
	66 **(66.00)**	34 **(34.00)**
Disposal of animal bodies in case of death	Not-Satisfactory **(0)**	Satisfactory **(1)**
	0 **(0.00)**	100 **(100.00)**

(Figure in parenthesis indicate percent)

3.2.5 Water Management:

Milk production needs a high quantity of water, which may have a significant impact on the cost of production as well as potential negative effects on the environment. At the dairy farm, water is commonly used for drinking, cooling systems, washing facilities and equipment, irrigation, and domestic use (IHDB, 2015). Dairy farmers can reduce their water footprint by implementing practices that can include proper feeding of animals and monitoring of water consumption, adequate ventilation of facilities, as well as maintenance and repair of water, wastewater, and irrigation systems. Proper water management in dairy farms is important to prevent pollution from fertilizers, pesticides etc. The water management conditions of dairy farms of the respondents is depicted in Table 1.

Water management practices followed by 62 percent faremrs were not-satisfactory whereas 38 percent dairy farmers found following satisfactory water management practices in the study area. Similar trends were reported by Singh &Hansra (2021) and Rahman (2011).

3.2.6 Preparedness to drought:

Irrigation water is crucial for dairy farming. Dairy farming is an intensive agriculture with requirement of water to sustain farm potential. Dairy farming is practiced on steep hill farms in study area where it is very much required that dairy farms are prepared for irregular water supply and erratic rainfall. Analysis of data presented in Table 1, reveal that majority of the respondents (82.00 per cent of dairy farmers) were not prepared for drought whereas only 18 percent farmers have preparedness to drought. Singh & Hansra (2021) and Rehman (2011) observed similar trends for preparedness of flood in a research conducted in Himachal Pradesh and Assam respectively.

3.2.7 Disposal of medicine and feed packaging:

Analysis of data reveals that majority of the respondents 60.00 per cent of farmers were disposing old medicine and feed packaging in very casual way which is not satisfactory whereas only 40.00 percent dairy farmers were found to dispose medicine and feed packaging in satisfactory way.

3.2.8 Animal urine disposal:

Urine from dairy animals, a byproduct of the livestock industry, raises environmental concerns due to its potential to pollute water sources and release greenhouse gases. Improper disposal can clog drainage systems, contaminate water supplies, and create breeding grounds for disease-carrying pests. The management of animal urine on dairy farms is a key indicator of environmental sustainability, as it has a direct impact on both water quality and greenhouse gas emissions. Analysis of data reveals that animal urine was disposed –off in open in un-satisfactory way by majority of the respondents (66.00 per cent) whereas only 34.00 percent of the dairy farmers were found to have satisfactory urine underground disposal system.

3.2.9 Disposal of animal bodies in case of death:

Dead animals are potentially dangerous because their death may be caused by infection with contagious diseases, like the bacteria that live on the flesh and wool of dead animals. These microbes can resist the harsh external environmental conditions for several years. These microbes may spread via air, which means increasing the scope of contamination. (Dead animals, 1995; Ristić et al., 2013). Death animals' bodies' decomposition add harmful gases to the environment and release toxic substances which is threat to environmental sustainability. Hence way to dispose dead animals is also an important indicator of environmental sustainability of dairy farms. In present study data was collected about handling dead animals ie buried at proper place (satisfactory) or kept in an isolated place (un-satisfactory). As data placed in Table 1 reveal that 100 percent of the farmers were disposing dead animal to the satisfactory level.

TABLE 2
ENVIRONMENTAL SUSTAINABILITY INDEX (ENSI) OF DAIRY FARMS

Respondents	Level of sustainability			
	Least Sustainable (0-0.25)	Moderately Sustainable (0.26-0.50)	Sustainable (0.51-0.75)	Highly sustainable (0.76-1.00)
Members (n=100)	3 **(3.00)**	51 **(51.00)**	42 **(42.00)**	4 **(4.00)**

(Figure in parenthesis indicate percent)

3.3 Environmental sustainability of dairy farms of the respondents:

To find out environmental sustainability index (EnSI) of the farms, the above discussed indicators were used and data is presented in Table 2. The EnSI of dairy farms range from 0.22 to 0.84. Majority of the dairy farms (51.00 percent) were found moderately sustainable followed by sustainable farm (42.00 %). Leishangthem et al (2017) also reported majority of farms in moderate category of sustainability and similar trend of results reported by Singh and Hansra (2021), Rehman (2011) for farming studies

IV. CONCLUSION

The environmental sustainability of dairy farms is a complex yet critical concern, especially in regions where traditional practices intersect with modern demands. This study, by employing key indicators such as animal health, housing conditions, calf rearing, water management, drought preparedness, waste disposal methods, and manure usage, provides a comprehensive overview of sustainability practices followed by dairy farmers. The findings reveal that while certain aspects—like animal health care (76%), calf raising (85%), use of dung as manure (95%), and proper disposal of dead animals (100%)—are being addressed with commendable diligence, other indicators demonstrate significant gaps. Notably, areas such as drought preparedness (only 18% satisfactory), water management (38%), and disposal of medicine/feed packaging and animal urine remain weak points that require immediate attention. The Environmental Sustainability Index (EnSI) calculated in the study further emphasizes these disparities. With 51% of farms categorized as moderately sustainable and only 4% reaching high sustainability, it is evident that most farms operate below optimal environmental standards. These results align with previous research, confirming that environmental sustainability in dairy farming remains an area needing concerted policy support, technological intervention, and farmer awareness. In conclusion, while there is encouraging progress in some practices, comprehensive improvement across all indicators is essential. Strengthening education and extension services, promoting eco-friendly technologies, and enhancing access to sustainable infrastructure will be pivotal in transitioning more dairy farms towards higher environmental sustainability. Only with integrated, science-based efforts can the dairy sector ensure long-term ecological balance while sustaining livelihoods.

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Cluster and Principal Component Analysis for Seed Coat Resistibility and Its Related Traits of Cotton (*Gossypium spp.*) Genotypes

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***Abstract*—** *During the ginning of seed cotton, the seeds can be broken and mixed into the fibers. The number of seed coat particles passing into the fibers and the amount of neps caused by the seed coat is an important factor that negatively affects the yarn quality and creates problems in dyeing. In this study, 200 different cotton genotypes were evaluated in terms of 100-seed weight, seed coat ratio, seed coat thickness and seed coat resistibility. As a result of the study, it was determined that 100-seed weights of genotypes varied between 7.23 - 15.43 g, seed coat ratios between 15.53 - 38.27%, seed coat thickness between 0.41 - 1.00 mm and seed coat resistibility between 41.07 - 107.21 newton. TxNo:142 genotype had the highest seed coat resistibility. In addition, it was determined that there was a positive and significant relationship between seed coat resistibility and 100-seed weight. In principal components analysis, two out of 4 principal components were selected with Eigen value >1. The two principal components contributed 59.3% towards variability. In cluster analysis, 200 genotypes were allocated in five clusters. Cluster II was the largest by having 90 genotypes while cluster V, cluster III, cluster I and cluster IV having 54, 28, 20 and 8 genotypes, respectively.*

Keywords*— *Cotton, seed traits, seed coat.

I. INTRODUCTION

Cotton, which constitutes the raw material of more than fifty industries, especially the textile and food industries, is one of the most important industrial plants. Cotton is the raw material of the textile and cellulose industry with its fiber, of the vegetable oil industry with the oil obtained from the kernel, and of the feed industry with its seed and meal. Approximately 90% of the fiber crops cultivation areas in the world are cotton. In our country, according to 2024 data, cotton was cultivated on approximately 467 000 hectares and 2.24 million tons of seed cotton was produced (Anonymous, 2024). According to Aydın Commodity Exchange data, in the 2023/2024 season, Turkey is the fourteenth country in terms of cultivation area, sixth in terms of fiber cotton yield obtained from unit area, seventh in terms of fiber cotton production amount, fifth in terms of fiber cotton consumption and fourth in terms of fiber cotton imports in the world cotton market (Anonymous, 2023).

Seed cotton harvested from the field contains fibers and kernels before processing. In order for the seed cotton to be sent to spinning mills, it must be cleaned from the kernels and other foreign materials (vegetable parts, dust, etc.). The process of separating cotton into kernel and fiber is called ginning (Kıllı, 2001). After the ginning process, fiber cotton is obtained as the main product and cotton seed is obtained as a by-product. On average, 35-40% of the seed cotton consists of fiber and 60-65% of seed.

The seed cotton obtained after harvesting is separated from the seeds by ginning. During ginning, the seeds may break and mix with the fiber cotton. After ginning, the number of seed coat particles and the amount of neps caused by seed coat is an important problem that negatively affects the yarn quality, creates problems in dyeing and reduces the quality and value of textiles (yarn and fabric). In our country, approximately 40% of baled cotton has seed coat problem (Özbek, 2017). The cotton seed coat has a 5-layered structure (Figure 1) (Yan et al., 2009).

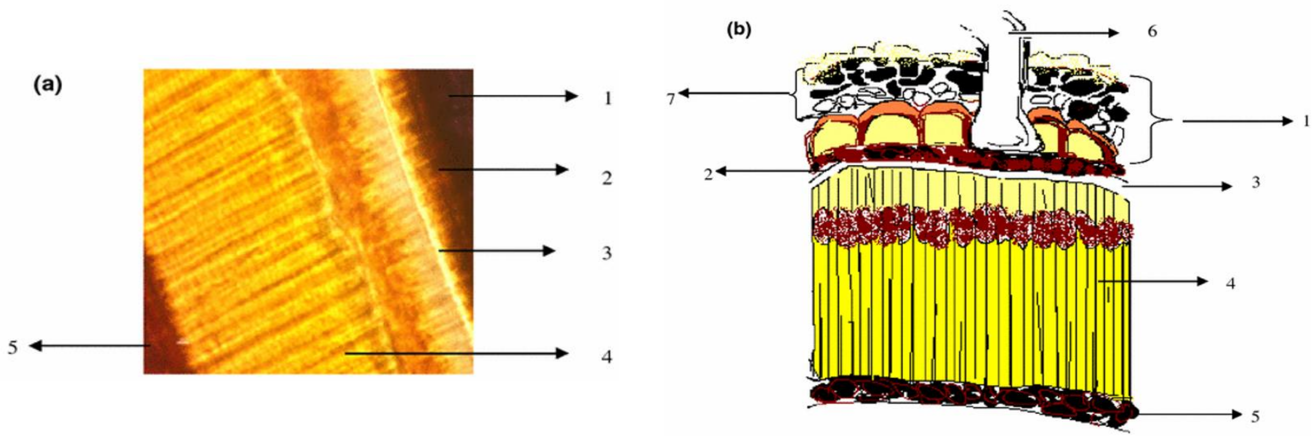

FIGURE 1: Cotton seed coat structure a) Light microscope image of seed coat section b) Schematic view of seed coat anatomical structure. 1) epidermis layer, 2) outer pigment layer, 3) colorless layer, 4) palisade layer, 5) inner pigment layer, 6) cotton fiber, 7) cutin (Yan et al., 2009).

Cellulose and pectin are the main components of the epidermal layer surrounded by cutin and wax; pectin, hemicellulose and lignin are the main components of the palisade layer; and lignin-like compounds are the main components of the inner and outer pigment layer (Yan et al., 2009). During the ginning of seed cotton after harvest, seed coats can be broken and mixed into the fibers. Approximately 30% of the negative effects in textile products are attributed to seed coat particles and it is emphasized that seed coat particles in ginned fiber cotton can vary by 50% depending on cotton varieties (Bel and Xu, 2011).

Principal component analyses (PCA) and biplot approaches are an approach that provides the opportunity to visually present and evaluate the relationships between the examined parameters and genotypes at the same time (Kahraman et al., 2021). There is a need to use principal component analysis to demonstrate the results of cotton breeding research. Therefore, many researchers (Abasianyanga et al., 2017; Nandhini et al., 2018; Shah et al., 2018; Vinodhana and Gunasekaran, 2019; Abdel-Monaem et al., 2020; and Yehia and El-Hashash, 2021) have used PCA to know the relationships among yield and yield components, as well as to evaluate the relationship and diversity among various cotton germplasms. This study aimed to evaluate the genotypes and the relationship between seed coat breaking resistance and seed weight, seed coat ratio and seed coat thickness traits in 200 different cotton genotypes.

II. MATERIALS AND METHODS

2.1 Experimental site:

The experiment was conducted in the research area of the Department of Field Crops, KSU Faculty of Agriculture, during the 2018 cotton growing season. The province of Kahramanmaras, where the experiment was conducted, is located between 37°11' and 38°36' north latitude and 36°15' and 37°42' east longitude. The average temperature and precipitation during the experimental years (2018) and the long-term averages over time are presented in Figure 2. The average temperature of May - November in the research year and long years were 18.54°C and 17.47°C, respectively. The total monthly precipitation in May - November was 240.4 mm and the average monthly relative humidity was 56.09%. There was no precipitation in July, August and September. The soils of the test area have a clay loam texture with a pH of 7.72, salinity of 0.15% and low organic matter content (1.55%).

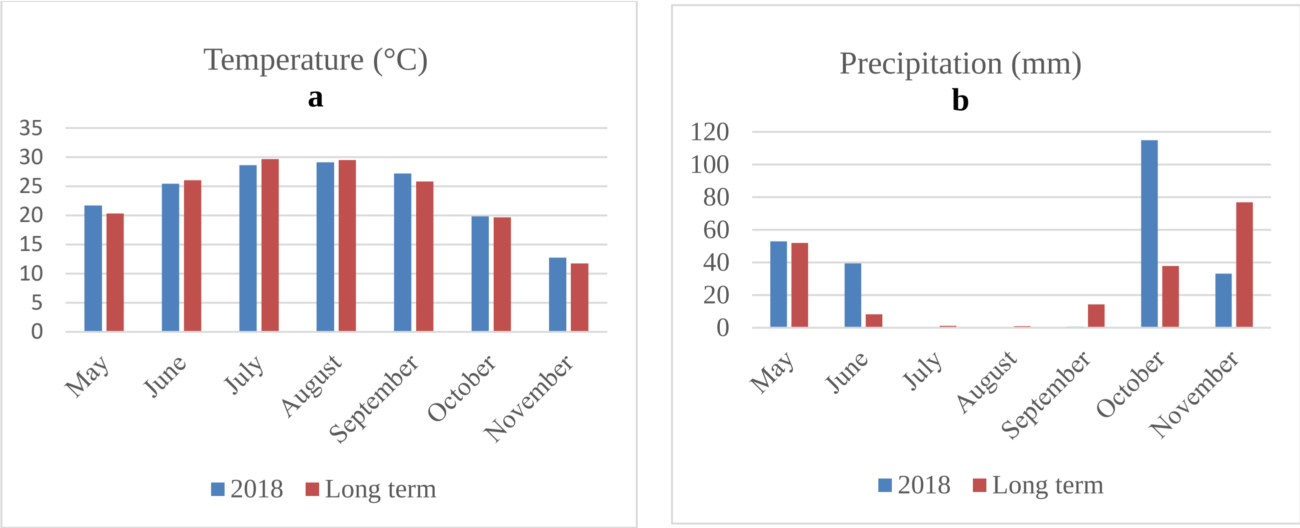

FIGURE 2: The average climate data for the experimental years; (a) Temperature; (b) Precipitation

2.2 Experimental materials:

In the study, 200 different cotton genotypes obtained from the genetic stocks of Nazilli Cotton Research Institute (CRI-Nazilli/Turkey) were used as material. The sequence numbers and names of the cotton genotypes used are given in Table 1.

2.3 Experimental design and field management:

The research was carried out according to the randomized block design with three replications. The experimental area was plowed deeply with a plow in the fall, and after spending the winter in this way, it was made ready for sowing by cultivating the soil with a cultivator and tapping it while the soil was at the right level before sowing according to the weed status of the field. The seeds of the varieties used in the experiment were sown by hand on May 11, 2018 in 5 m long plots with a row spacing of 70 cm in accordance with the experimental design. After emergence, cotton seedlings were thinned by hand in the 2- to 4-leafed period with a row spacing of 20 cm. Before sowing, 300 kg of 20-20-0 compound fertilizer containing 60 kg N and P_2O_5 per hectare was applied as sprinkling. As a top fertilizer, 200 kg ha^{-1} of urea fertilizer containing 46% nitrogen was applied by hand before the second irrigation. In order to protect the developing cotton seedlings from weeds, to prevent the loss of water in the soil by evaporation, to ensure the development and deepening of the roots of the seedlings, hand hoeing was done 2 times and tractor hoeing 3 times. Cotton plants were irrigated 7 times during the vegetation period by furrow irrigation method, taking into account their development status. During the growing season, cotton plants were sprayed four times against sucking insects (*Aphis gossypii* and *Empoasca spp*) and once against green bollworm (*Helicoverpa armigera*) pests. Harvesting was done twice by hand on October 8 and November 1, 2018.

TABLE 1
AVERAGE VALUES OF 200 COTTON GENOTYPES FOR INVESTIGATED CHARACTERS

Genotype No	Genotype name	100-SW (g)	SCR (%)	SCT (mm)	SCRe (Newton)
1	MNH-786	9,02	29,54	0,56	62,26
2	BH-118	9,99	33,72	0,67	47,30
3	Ziroatkar-68	11,59	31,85	0,63	66,90
4	Sindh-1	9,71	29,50	0,66	68,46
5	AGC 85	11,55	34,63	0,50	59,84
6	CIM 401	9,27	34,16	0,76	71,69
7	Frego Cluster	10,36	26,07	0,49	69,87
8	AzGR-11468	11,90	29,97	0,66	67,28
9	CIM-506	10,63	19,34	0,56	53,01
10	Sohni	8,60	29,54	0,58	66,82
11	CIM-70	10,21	19,68	0,55	54,91
12	994	9,87	25,42	1,00	45,53
13	VH 260	9,43	22,25	0,61	44,89
14	Stoneville 474	9,85	38,27	0,54	79,72
15	Malmal-MNH-786	9,34	20,33	0,60	55,05
16	AzGR-11836	11,01	32,15	0,62	82,08

17	Marvi	8,42	30,88	0,49	55,38
18	Ziroatkar-81	12,29	23,85	0,47	75,65
19	AzGR-11834	11,43	22,17	0,42	82,53
20	AzGR-11839	12,29	19,50	0,58	80,87
21	Stoneville 506	10,45	27,38	0,45	69,06
22	Nibge-2	11,02	20,55	0,69	67,56
23	MNH-990	8,97	33,06	0,52	66,50
24	Sadori	10,06	29,63	0,49	57,37
25	Penta	11,35	29,36	0,54	86,79
26	Abroginal 79	9,91	33,29	0,60	71,46
27	Nova	10,95	29,25	0,98	73,10
28	Shazbaz	7,72	27,64	0,48	45,72
29	Deltapine 5816	11,57	34,10	0,51	82,68
30	Deltapine 565	12,87	32,63	0,52	71,84
31	Stoneville 2B	10,39	30,48	0,43	70,43
32	Deltapine 50 –vert	9,06	31,54	0,56	58,32
33	MNH-493	7,37	33,44	0,57	47,15
34	Stoneville 508	10,83	29,84	0,55	86,37
35	AzGR-7711	12,53	33,56	0,70	71,68
36	Stoneville 256	10,75	21,69	0,67	74,65
37	Stoneville 5A	10,92	27,75	0,65	80,57
38	Tamcot Sphinx	10,05	25,55	0,57	72,16
39	Bulgar 73	10,90	29,70	0,59	79,11
40	Stoneville 618 BBR	9,02	29,31	0,41	99,38
41	Carolina Queen	9,79	27,19	0,60	80,13
42	AfricaES(20025)	10,33	36,25	0,56	81,22
43	Acala Tex	11,32	36,27	0,67	75,01
44	Tx No: 1412	11,11	17,31	0,55	107,21
45	Karnak 55	13,68	18,03	0,94	102,54
46	Mex 106	14,60	33,66	0,47	92,76
47	Dpl 5540-85-subokra	11,59	24,39	0,50	78,39
48	Deltapine 120	11,48	23,61	0,57	73,63
49	Acala 1517-70	11,43	28,30	0,57	79,93
50	TAM C155 - 22 ELS	11,66	27,48	0,48	88,31
51	Deltapine 45 – vert	13,61	21,46	0,66	71,82
52	Acala 44	13,94	27,50	0,61	91,41
53	Deltapine 15A	11,87	26,44	0,57	79,22
54	Brown Egyptian	9,96	21,84	0,55	72,35
55	Deltapine 12	12,20	24,11	0,61	78,00
56	Deltapine 25	9,96	29,13	0,69	92,55
57	Acala Nunn's	10,53	33,31	0,59	75,52
58	Acala 1517 D	7,23	31,03	0,51	101,63
59	Acala Morell	12,59	32,72	0,48	89,14
60	TAM B147 – 21	11,81	31,50	0,57	83,65
61	TAM 87 G3- 27	12,06	31,47	0,48	69,74
62	Acala Glandless	10,46	26,17	0,65	86,84
63	Acala 4-42	14,27	26,51	0,57	79,66
64	Acala 442	12,69	20,16	0,69	92,25
65	TAM C66 - 26	14,56	28,33	0,57	82,55
66	Deltapine Staple	11,88	30,29	0,47	79,52
67	Togo	11,66	25,41	0,58	71,97
68	NIAB-KIRN	12,33	39,58	0,52	76,97
69	Sivon	8,99	30,21	0,58	75,64
70	Alba Acala 70	11,25	20,47	0,65	74,19
71	NIA-UFAQ	12,22	29,09	0,45	59,24
72	Giza 7	9,05	26,17	0,54	77,99
73	Cris-134	11,21	23,35	0,49	58,21
74	Acala Naked	8,70	26,13	0,62	78,34

75	Samos	10,73	27,31	0,47	71,88
76	Agdas 6	10,62	34,87	0,49	73,74
77	Zeta 2	11,95	34,07	0,49	77,69
78	Agdas 7	11,78	32,92	0,44	75,71
79	AGC 375	9,82	27,21	0,45	73,58
80	Haridost	10,66	21,10	0,64	59,51
81	Viky (ES-20021)	9,64	29,57	0,57	65,09
82	Sorbon	9,68	31,70	0,44	80,09
83	Agdas 3	8,04	27,99	0,52	79,38
84	Sugdiyon-2	10,11	22,33	0,59	81,85
85	CIM-240	12,41	25,32	0,51	77,45
86	Sure Grow 125	10,26	30,49	0,63	69,41
87	AzGR-3775	9,72	25,50	0,55	83,62
88	Ujchi 2 Uzbek	11,36	26,42	0,62	87,51
89	Ziroatkar-64	10,71	29,73	0,58	79,77
90	AGC 208	9,97	22,28	0,55	71,31
91	B557	10,31	30,65	0,43	56,92
92	Cris-342	8,37	31,10	0,53	64,85
93	MNH-814	9,21	23,97	0,57	43,34
94	Korina	9,73	24,16	0,50	76,67
95	FH 142	10,61	28,96	0,83	41,07
96	TX No: 1416	8,16	15,53	0,58	84,18
97	Stoneville 213	14,38	30,19	0,50	73,03
98	Acala SJ 3	9,71	33,70	0,51	76,09
99	Mex 123	10,28	38,52	0,62	73,37
100	Fibermax 832	10,20	27,61	0,49	69,66
101	Giza 75	9,78	24,46	0,60	84,68
102	Tex 844	12,26	23,48	0,60	81,06
103	Tx No: 2383	11,93	25,79	0,54	83,16
104	Bulgar 6396	11,02	26,31	0,55	82,59
105	Deltapine 20	10,14	28,87	0,49	77,05
106	Agala Sindou	10,16	22,92	0,51	70,33
107	Tex 1152	10,03	25,92	0,48	70,18
108	NIAB 111	12,07	35,10	0,59	67,91
109	Mehrgon	9,80	29,36	0,45	82,44
110	Campu	10,66	26,71	0,59	74,64
111	Stoneville 3202	11,72	26,43	0,79	74,47
112	Stoneville 62	10,27	30,59	0,51	72,92
113	Giza 70	10,80	27,95	0,58	66,28
114	Deltapine 62	10,61	25,23	0,61	75,55
115	Acala Okra	11,49	31,19	0,49	78,08
116	Acala Young's	10,05	27,48	0,58	73,27
117	TAM B182	10,91	26,68	0,73	76,78
118	Deltapine SR-5	13,73	32,60	0,61	75,65
119	TAM C147 -42	10,14	27,93	0,51	70,69
120	Acala 8	11,93	27,44	0,45	79,25
121	Acala 1064	12,30	21,11	0,48	76,72
122	Acala Cluster	10,79	28,08	0,60	77,18
123	Auborn 56	9,96	23,15	0,48	70,85
124	TAM 94 L 25 P1	10,82	27,59	0,55	68,23
125	Aden	12,32	35,70	0,49	86,46
126	Acala Okra VA2-4	10,55	31,36	0,69	78,28
127	Deltapine 905	12,11	32,87	0,64	76,96
128	Acala 29	10,95	18,23	0,71	78,45
129	Giza 45	13,01	23,60	0,63	74,62
130	Earlipima	12,28	21,60	0,70	82,22
131	Acala 1517 SR2 – vert	15,43	25,88	0,82	73,94
132	Acala N 28-5	12,23	25,88	0,53	66,84

133	Deltapine 26	10,18	28,13	0,60	72,17
134	AzGR-11835	11,14	26,64	0,65	75,29
135	Rantos	11,51	20,99	0,61	70,40
136	Agdas 17	12,38	27,67	0,95	78,82
137	NIAB-111	11,56	29,07	0,61	50,70
138	Tex 1216	9,97	25,29	0,48	78,42
139	Mex 122	12,13	26,16	0,56	77,46
140	Tx No: 2700	11,60	24,39	0,57	80,23
141	Stoneville 014	12,27	26,57	0,56	70,47
142	Stonville 108 SR	11,02	22,51	0,61	67,56
143	TX No: 2382	11,99	22,97	0,51	74,69
144	Hopicala – vert	12,33	26,25	0,50	75,43
145	Eva	12,44	26,62	0,55	70,12
146	Mex 102	10,53	23,56	0,53	77,24
147	NIAB 78	11,32	28,12	0,72	63,94
148	Stoneville 731N	10,09	24,83	0,70	73,24
149	Taashkent	11,00	26,18	0,49	99,65
150	Stonville 504	10,86	27,20	0,55	64,36
151	Cascot L7	10,67	28,46	0,61	73,40
152	Avesto	11,02	18,27	0,48	61,61
153	Darmi	11,07	25,82	0,63	86,54
154	Giza 59	12,15	26,09	0,59	78,80
155	Tadla 25	11,87	23,70	0,71	72,76
156	New Mexican Acala	11,82	27,31	0,73	79,44
157	Giza 83	12,45	22,91	0,53	79,59
158	Stoneville 256-315	12,68	22,43	0,49	79,55
159	Arcota-129	12,19	24,85	0,53	65,40
160	NIAB 846	11,67	26,82	0,56	59,58
161	Mex 68	10,07	20,76	0,48	77,01
162	Europa	12,84	23,83	0,54	82,74
163	TX No: 1389	11,74	18,70	0,59	75,98
164	Ionia	12,28	28,00	0,54	75,88
165	Helius	11,31	23,97	0,53	75,96
166	NIAB 874	12,11	21,38	0,51	63,61
167	Ligur	11,22	25,75	0,58	74,79
168	NIAB 777	10,36	23,77	0,58	64,03
169	Tex 2167	10,51	27,90	0,48	69,54
170	Fibermax 819	11,13	31,72	0,58	67,76
171	Tex 843	10,51	27,54	0,50	76,07
172	Acala 32	11,12	31,50	0,52	78,92
173	Acala 1-13-3-1	10,47	28,04	0,60	60,63
174	Deltapine 61	12,83	35,17	0,64	71,45
175	Deltapine 15	10,85	27,41	0,65	69,47
176	Deltapine 14	10,58	35,77	0,58	72,52
177	Acala Shafter Station	9,40	28,35	0,48	72,86
178	Acala 1517-91	10,11	24,78	0,72	91,65
179	Acala Tex	12,18	25,01	0,80	77,24
180	Deltapine 714 GN	12,18	32,49	0,60	68,98
181	Acala 1517 C	10,87	27,45	0,63	69,90
182	Acala 44 WR	11,65	23,04	0,52	78,87
183	Deltapine 50	12,29	25,69	0,54	73,83
184	Acala SJ1	10,87	21,85	0,56	83,77
185	Crumpled	12,51	20,75	0,64	92,68
186	Deltapine 41	13,49	31,62	0,60	68,22
187	TAM C66 - 16	10,11	28,20	0,57	73,70
188	TAM 01 E - 22	14,35	31,31	0,54	70,46
189	Acala Harper	12,70	29,02	0,51	60,62
190	Acala-55-5	10,68	25,69	0,50	67,54

191	Deltapine 80	10,12	26,38	0,55	83,10
192	Tropical 225	10,63	23,62	0,51	77,88
193	TAM 04 WB - 33	13,28	25,97	0,58	74,83
194	Acala Mexican	12,07	27,67	0,54	89,12
195	Acala 3080	11,85	30,59	0,49	80,84
196	Acala 51	11,99	25,96	0,53	80,66
197	TAM A106- 16ELS	11,95	34,92	0,58	80,24
198	TAM B139 - 17 ELS	11,95	28,62	0,62	75,25
199	Deltapine SR4	12,66	29,59	0,60	83,28
200	Acala SS 2280	10,46	23,23	0,59	77,59
Average		11,09	27,35	0,57	74,20

2.4 Data collected:

100 seed weight (100-SW, g): Harvested seed cotton from each plot was ginned in micro ginning machine and seeds were obtained. From the seeds obtained by ginning, 100 cotton seeds were counted 4 times, weighed and averaged.

Seed coat ratio (SCR, %): One hundred seed samples from each plot were delinted with dilute sulphuric acid (50%) and weighed after drying for 48 hours under room conditions (Boykin, 2010). The seeds were then cut in half with a scalpel and the inner parts were removed. After weighing the shells obtained, the seed coat ratio was calculated as percentage according to the following formula.

SCR (%) = [100 seed coat weight (g) / 100-SW (g)]) x 100 (1)

Seed coat thickness (SCT, mm): The hulls of 100 cotton seeds were measured from 3 different places with a digital caliper and the seed coat thickness was determined by averaging (Boykin, 2010).

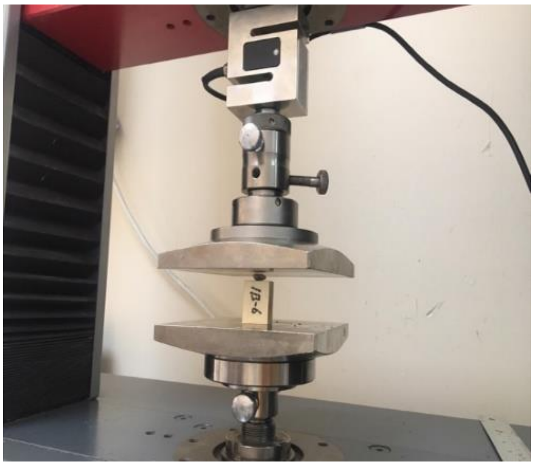

FIGURE 3. HIT5, 5P by ZwickTM instrument

Seed coat resistibility (SCRe, Newton): It was determined by working on 10 seed samples in 3 replicates (10x3= 30 seeds) randomly selected from the seeds obtained as a result of ginning the cotton harvested from each plot. Seed coat resistibility was determined by applying Zwick 10kN pressure at a speed of 2 mm min^{-1} on HIT5.5P by ZwickTM device (Figure 3) to seeds containing 8.0±0.5% moisture in KSU Faculty of Forestry test laboratory (Mengeloglu et al., 2015).

2.5 Data analyses:

The variance analyses of the data obtained for the traits examined in the study were carried out using SAS statistical package programme according to the random blocks experimental design. Duncan multiple comparison test was applied to compare the means of the significant sources of variation. Due to the high number of genotypes, averages for each trait were given and letter groupings were not shown. Pearson correlation analysis was utilized to examine the relationships between the traits (Sarwar et al., 2021). Principal component analyses were calculated on average data and evaluated with the biplot approach (JMP 15.1 SAS Institute Inc, 2020). Cluster analysis was based on SCRe and related seed traits. Cluster analysis was conducted following the agglomerative hierarchical clustering ward's method, in order to categorize genotypes into different homogeneous groups using XLSTAT (XLSTAT, 2014).

III. RESULTS AND DISCUSSION

Analysis of variance for investigated characteristics are presented in (Table 2). The result showed the existence of highly significant ($P \leq 0.01$) variation among genotypes for 100-SW, SCR, SCT and SCRe.

TABLE 2
MEAN SQUARES FROM ANALYSIS OF VARIANCE FOR 4 CHARACTERS OF 200 COTTON GENOTYPES

Source of variance	DF	100-SW	SCR	SCT	SCRe
Replication	2	0.56	27.78	0.0026	34.87
Genotype	199	5.48**	73.62**	0.0200**	329.35**
Eror	398	0.14	11.35	0.0051	51.31
CV %		3.43	12.24	12,31	9,66

, ** , ns, significant at $P \leq 0.05$, $P \leq 0.01$ and non-significant, respectively. 100-SW: Hundred seed weight, SCR: Seed coat ratio, SCT: Seed coat thickness, SCRe: Seed coat resistibility.

3.1 100-SW (g):

Cotton genotypes showed statistically significant difference in terms of 100-SW at p<0.01 level (Table 2). The average 100-SW value of the cotton genotypes used as material in the study was 11.04 g and they varied between 7.23 g and 15.43 g (Table 1). The highest 100-SW values were obtained from Acala 1517 SR2-vert (15.43 g), Mex 106 (14.60 g), TAM C66-26 (14.56 g) and Stoneville 213 (14.38 g) genotypes; the lowest 100-SW values were obtained from Acala 1517 D (7.23 g), MNH-493 (7.37 g) and Shazbaz (7.72 g) genotypes, respectively. Patel et al. (2003) reported that 100-SW values differed among cotton varieties; Efe et al. (2013) reported that 100-SW values of some mutant cotton varieties from Azerbaijan varied between 9.4 - 12.7 g in Southeastern Anatolia Region; Yuka (2014) reported that 100-SW values of 13 different cotton genotypes varied between 8.13-10.71 g; Tekeli (2016) reported that 100-SW values varied between 9.03-13.28 g; Kıllı and Beycioglu (2020a) reported that 100-SW values varied between 9.34-13.05 g in their study with 46 different cotton genotypes; Kıllı and Beycioglu (2020c) reported that 100-SW values varied between 9.11-12.65 g in different cotton genotypes. The fact that the 100-SW values obtained in the study showed a wide variation between approximately 7 g and 15 g and also differed from the findings of the researchers may be due to the presence of genotypes from different species and the high number of genotypes.

3.2 SCR (%):

Cotton genotypes showed statistically significant difference in terms of SCR at p<0.01 level (Table 2). The average SCR value of the cotton genotypes used as material in the study was 27.35 % and the SCR values varied between 15.53 % and 38.27 % (Table 1). The highest SCR values were obtained from Stoneville 474 (38.27 %), Acala Tex (36.25 %) and Africa ES (20025) (36.27 %) genotypes; the lowest SCR values were obtained from TxNo: 1416 (15.53 %) and TxNo: 1412 (17.31 %) genotypes, respectively. The wide variation between 15 % and 38 % of the SCR values obtained in the study was due to the presence of genotypes from different species, the large number of genotypes, and the different values of SCT and 100-SW.

3.3 SCT (mm):

Cotton genotypes showed statistically significant difference in terms of SCT at p<0.01 level (Table 2). The average SCT value of the cotton genotypes used as material in the study was 0.57 mm and SCT values varied between 0.41 mm and 1.00 mm (Table 1). The highest SCT values were obtained from Genotypes 994 (1.00 mm), FH 142 (0.83 mm) and Acala 1517 SR2-vert (0.82 mm); the lowest SCT values were obtained from Genotypes Stoneville 618 BBR (0.41 mm), Stoneville 2B (0.43 mm), B557 (0.43 mm), Agdaş 7 (0.44 mm) and Sorbon (0.43 mm), respectively. The wide variation between 0.41 mm and 1.00 mm in the SCT values we obtained in the study may be due to the presence of genotypes from different species, the number of genotypes being quite high, and the different SCR and 100-SW values.

3.4 SCRe (N):

The cotton genotypes used as material in the study showed statistically significant differences at p<0.01 level in terms of SCRe (Table 2). The average SCRe value over all genotypes was 74.20 N and SCRe values varied between 41.07 N and 107.21 N (Table 1). The highest SCRe values were obtained from TxNo:142 (107.21 N), Karnak 55 (102.54 N), Acala 1517D (101.63 N), Taashkent (99.65 N) and Stoneville 618 BBR (99. 38 N) genotypes; the lowest SCBR values were obtained from FH 142 (41.07 N), MNH-184 (43.34 N), VH 260 (44.89 N), Genotype 994 (45.53 N), Shazbaz (45.72 N), MNH 493 (47.15 N) and BH

118 (47.30 N) genotypes, respectively. Bolek et al. (2007) reported that the difference between varieties was significant in the study in which they investigated the SCR of 10 cotton varieties of *G. hirsutum* L. species; Down et al. (2019) reported that cotton seeds with different genetic structure showed differences in terms of break resistance. The results of SCRe obtained in this study are similar to the findings of the researchers. The difference between the lowest and highest SCRe values obtained from the genotypes was quite high as 66 Newton. The wide variation of the genotypes in terms of SCRe was due to the presence of genotypes from different species and the high number of genotypes. Armijo et al. (2006 a and b) reported that the amount of seed coat neps was 3 times higher in cotton varieties with easily breakable seed coat. The seed coat problems encountered in post ginning fibre cottons can be reduced by developing varieties with more robust, in other words, less brittle seed coat characteristics or by transferring seed coat robustness to existing varieties.

3.5 Pearson's Correlation:

Basic statistics for the traits analysed show that there is a sufficient amount of variability among the 200 cotton genotypes (Table 3). When the basic statistics are analysed, it is seen that among the 4 traits studied, except 100 seed weight, the other traits have relatively high coefficients of variation. This situation shows that there is a possibility to obtain new individuals from the existing genotypes and to create new combinations by crosses in the selections to be made in terms of the aforementioned traits.

TABLE 3
SOME DESCRIPTIVE STATISTICS FOR INVESTIGATED TRAITS

Traits	Minimum	Maximum	Mean	Variance	Standard deviation	Coefficient of variation (%)
100-SW (g)	7,23	15,43	11,09	1,89	1,37	3.43
SCR (%)	15,53	39,58	27,35	19,66	4,43	12.24
SCT (mm)	0,41	1,00	0,57	0,009	0,095	12.31
SCRe (N)	41,07	107,21	74,20	111,84	10,57	9.66

Pearson's correlation coefficients showing the relationships between the 4 traits investigated in 200 cotton genotypes are given in Table 4. When the relationships between the traits were analyzed, it was determined that 100-SW showed positive but insignificant relationship with SCT (r=0.124) and positive and significant relationship with SCRe (r=0.249**). The relationships between other traits were not statistically significant.

TABLE 4
PEARSON'S CORRELATION COEFFICIENT BETWEEN TRAITS OF 200 COTTON GENOTYPES

	SCR	SCT	SCRe
100-SW	-0.033	0.124	0.249**
SCR		-0.108	-0.063
SCT			-0.044

3.6 Principal component analysis:

Variance is decomposed into its components for the conservation and utilization of genetic diversity. Principal component analysis (PCA) simplifies complex data by transforming the number of correlated variables into a smaller number of principal components ((Said and Hefny, 2021), it is also a useful technique for revealing suitable genotypes for successful breeding strategies (Nazir et al., 2013). In this study, two of the four principal components were selected with an eigenvalue >1 (Table 5). The contribution of PC-I and PC-II to the total variability was 59.3%, indicating that there is valuable information in the first two components. PC-I contributed the most (32.34%), followed by PC-II (27.03%), PC-III (23.38%) and PC-IV (17.25%).

The scatter plot plotted according to factor scores using principal components (Figure 4) shows that cotton genotypes were distributed in all 4 regions of the plot. This situation reveals the presence of genetic variation among genotypes belonging to different clusters. The genotypes that are close to each other and in the center on the graph are similar to each other in terms of the traits examined, while the genotypes that are far from the center differ in terms of the aforementioned features. A significant genetic diversity was observed among the analyzed commercial Turkish cotton varieties revealed by PCA analysis (Elçi et al., 2014). The same graph shows that there is a close relationship between seed coat resistibility and 100-seed weight.

TABLE 5
PRINCIPAL COMPONENT ANALYSIS OF DIFFERENT TRAITS OF COTTON GENOTYPES

Variable	PCI	PCII	PCIII	PCIV
Eigen value	1.293	1.0811	0.9354	0.6901
% of total variance	32.34	27.03	23.38	17.25
Cumulative variance %	32.34	59.36	82.75	100.00
Factors loading by various characters				
100-Seed weight (g)	0.763	0.163	0.329	-0.531
Seed coat ratio (%)	-0.362	0.533	0.746	0.168
Seed coat thickness (mm)	0.356	-0.729	0.471	0.345
Seed coat resistibility (Newton)	0.673	0.487	-0.221	0.511

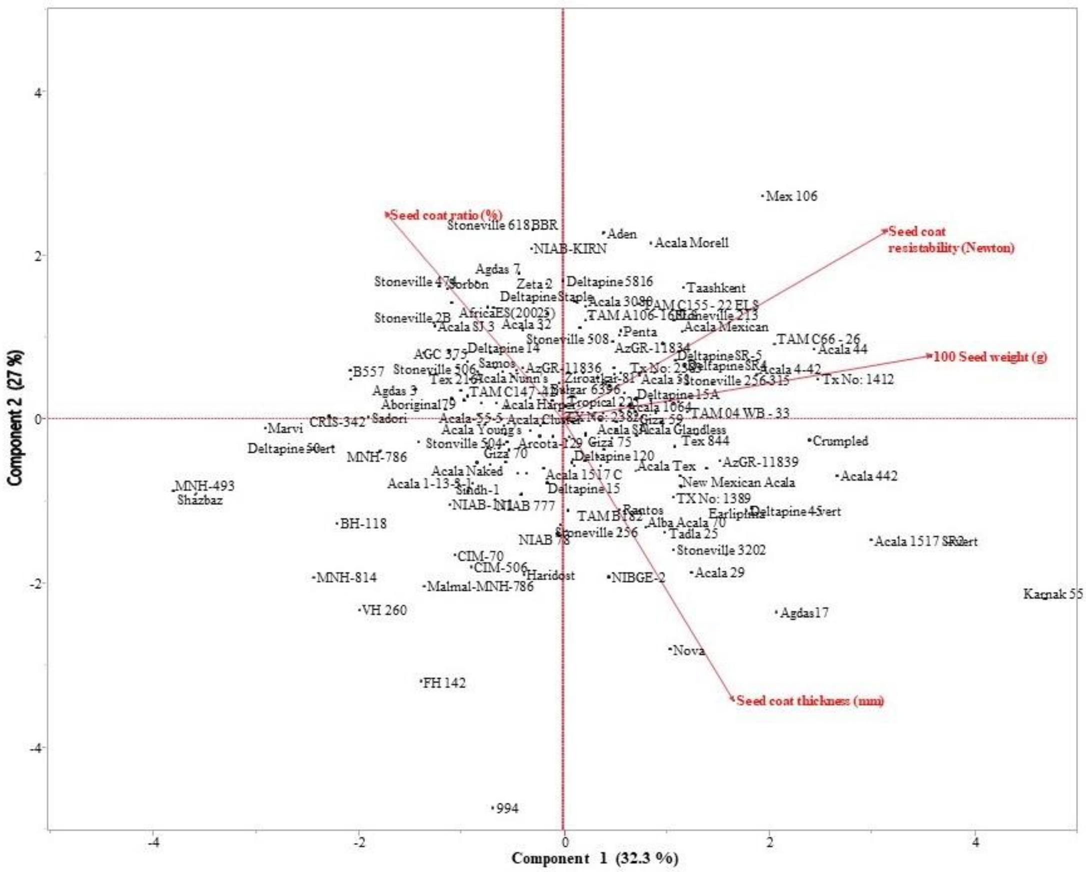

FIGURE 4: Biplot graphical display of the measured traits in 200 cotton (*Gossypium spp*.) genotypes.

3.7 Cluster analysis:

Cluster analysis showed that the 200 cotton genotypes were grouped into 5 clusters (Figure 5). This indicated the presence of disparity among the tested cotton genotypes. The cluster II, being the largest, comprised of 90 genotypes (45%) pursued by cluster V, cluster III, cluster I and cluster IV comprising 54 (27%), 28 (14%), 20 (10%) and 8 (4%) genotypes, respectively (Table 6). As seen in Table 7, cluster V displayed maximum values for all traits. Cluster analysis has been widely used to assess genetic distance, respectively genetic diversity, based on various traits among a given set of genotypes in cotton (Rathinavel, 2018; Jarwar et al., 2019; Sarwar et al., 2021; Valkova and Koleva, 2024). The dendrogram also showed the grouping of genotypes in clusters and sub-clusters (Figure 5). Based on cluster analysis the genotypes in cluster V may be utilized for incorporation of seed coat resistibility traits. The cluster IV may be further exploited in breeding programs for the development of cotton genotypes with high resistant seed coat traits along with desirable 100–seed weight and seed coat thickness.

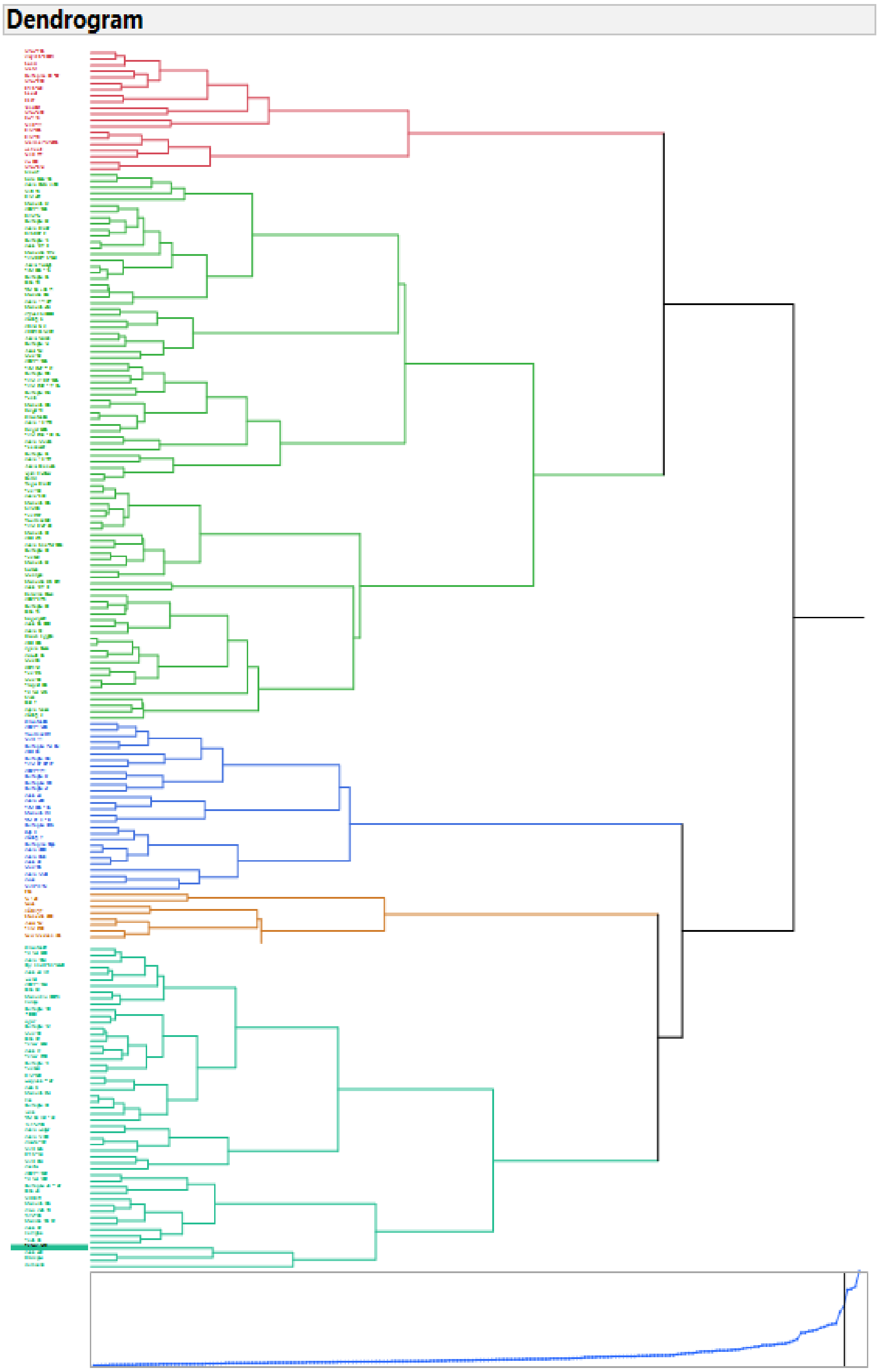

FIGURE 5: A dendrogram showing the position of genotypes in different clusters

TABLE 6
THE DISTRIBUTION OF GENOTYPES INTO 5 CLUSTERS FOR 200 COTTON GENOTYPES

Cluster	No of genotypes	Percentage (%)	Genotypes
I	20	10	1, 2, 9, 10, 11, 13, 15, 17, 23, 24, 28, 32, 33, 80, 81, 91, 92, 93, 108, 168
II	90	45	4, 6, 7, 14, 16, 21, 25, 26, 31, 34, 37, 38, 39, 40, 41, 42, 49, 50, 54, 56, 57, 58, 60, 62, 65, 69, 72, 74, 75, 76, 79, 82, 83, 84, 86, 87, 88, 89, 90, 94, 96, 98, 99, 100, 101, 104, 105, 106, 107, 109, 110, 112, 113, 114, 116, 119, 122, 123, 124, 126, 127, 131, 133, 134, 138, 146, 147, 148, 149, 150, 151, 153, 161, 169, 171, 173, 175, 176, 177, 178, 179, 181, 184, 190, 191, 192, 194, 197, 198, 199, 200
III	28	14	3, 5, 8, 29, 30, 35, 46, 52, 59, 61, 63, 66, 68, 77, 78, 97, 115, 118, 125, 137, 170, 172, 174, 180, 186, 187, 188, 195
IV	8	4	12, 27, 43, 95, 111, 117, 136, 156
V	54	27	18, 19, 20, 22, 36, 44, 45, 47, 48, 51, 53, 55, 64, 67, 70, 71, 73, 85, 102, 103, 120, 121, 128, 129, 130, 132, 135, 139, 140, 141, 142, 143, 144, 145, 152, 154, 155, 157, 158, 159, 160, 162, 163, 164, 165, 166, 167, 182, 183, 185, 189, 193, 196

TABLE 7
MEAN VALUES OF 4 CHARACTERS FOR 5 CLUSTERS OF 200 COTTON GENOTYPES.

Traits	Cluster I	Cluster II	Cluster III	Cluster IV	Cluster V
100 Seed weight	8.50	10.39	12.03	13.99	15.43
Seed coat ratio	18.80	23.30	27.80	32.90	37.80
Seed coat thickness	0.48	0.58	0.69	0.81	0.97
Seed coat resistibility	47.36	62.96	75.02	85.70	102.08

IV. CONCLUSIONS AND RECOMMENDATIONS

The analysis of variance revealed that there were sufficient variations among cotton genotypes for seed coat resistibility and its related traits. The results showed the presence of significant differences ($P \leq 0.01$) among the tested genotypes for all traits. Cluster analysis revealed that the 200 cotton genotypes were grouped into 5 clusters. The principal component analysis extracted two principal components PCA1 to PCA2 from the original data having Eigen values greater than one accounting nearly 59.3% of the total variation. Cluster analysis classified the 200 cotton genotypes into five distinct clusters contained 8-90 genotypes. This indicated the presence of diversity among the tested cotton genotypes. The relationships between traits identified through biplot analysis were consistent with Pearson's correlation coefficients, showing positive correlations between 100-seed weight and seed coat resistibility. A significant count of cotton genotypes are used in the study, and this diversity provides the opportunity to select genetic types with desirable seed coat resistibility trait for use in breeding programs.

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Impact of Agrochemicals on Human Health: A Review

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***Abstract*—** *The widespread use of agrochemicals, including fertilizers, pesticides, herbicides, and plant growth regulators, has greatly enhanced agricultural productivity worldwide. However, their long-term impact on human health and the environment has become a major concern. This paper investigates the health risks associated with agrochemical exposure, such as neurological disorders, cancer, endocrine disruptions, and cardiovascular diseases. It also explores exposure pathways, bioaccumulation, and biomagnification. Case studies, including the Endosulfan tragedy in India and the link between glyphosate and cancer risk, underscore the urgent need for stricter regulations and safer farming practices. The study highlights the importance of sustainable agriculture, organic alternatives, and increased awareness among farmers and consumers to reduce health risks while ensuring food security.*

***Keywords*— Agrochemicals, Pesticide exposure, Human health risks, Bioaccumulation, Sustainable agriculture.**

I. INTRODUCTION

For centuries, agriculture has been fundamental to human civilization, providing food security and economic stability. To enhance crop production and counter natural challenges, farmers increasingly relied on agrochemicals—chemical agents used to promote plant growth and control pests. The Green Revolution of the 1960s marked a major shift, introducing synthetic fertilizers, pesticides, and herbicides that significantly boosted food production (Pal *et al.,* 2006). However, while these chemicals contributed to higher yields, their long-term impact on human health and the environment has become a growing concern.

India, a major agricultural nation with 176.5 million hectares of farmland, depends heavily on agrochemicals to sustain its food supply (Wikipedia, 2024). Nearly half of the country's workforce is engaged in agriculture, with 59% of the rural population relying directly on farming for their livelihood (Statista, 2024). However, agricultural exports have declined from USD 55 billion in 2022 to USD 51 billion in 2023, partly due to quality control issues and contamination from excessive pesticide use (The Hindu Business Line, 2024).

Despite their advantages, agrochemicals have been linked to severe health risks, including neurological disorders, cancers, and endocrine system disruptions (Onder & Dursun, 2011). Farmworkers face regular exposure through direct handling, while consumers may ingest residues through contaminated food and water. Addressing these challenges is crucial for sustainable agriculture, ensuring both food security and public health.

II. TYPES OF AGROCHEMICALS AND THEIR EFFECTS ON HUMAN HEALTH

2.1 Fertilizers and Their Health Effects:

Fertilizers replenish essential soil nutrients, enhancing plant growth and agricultural productivity. However, excessive use can lead to adverse health and environmental consequences.

- **Nitrate Contamination:** Overapplication of nitrogen-based fertilizers causes nitrate leaching into groundwater. Elevated nitrate levels in drinking water have been linked to methemoglobinemia (blue baby syndrome) and gastrointestinal disorders (Bahadur *et al.,* 2015).

- **Heavy Metal Accumulation:** Some fertilizers contain trace amounts of toxic metals like cadmium, arsenic, and lead, which can accumulate in human tissues, increasing the risk of kidney damage, neurological disorders, and cancer (Gupta & Gupta, 2020).

2.2 Pesticides and Their Health Effects:

Pesticides are used to control agricultural pests, but their residues persist in food and the environment, posing significant health risks.

- **Insecticides:** Organophosphates and carbamates inhibit acetylcholinesterase, an enzyme essential for nerve function. Chronic exposure has been linked to cognitive decline, memory loss, and, in severe cases, paralysis (Sunkara, 2023).
- **Herbicides:** Glyphosate, one of the most widely used herbicides, has been classified as a probable human carcinogen (De Roos *et al.,* 2005). Long-term exposure has been associated with an increased risk of non-Hodgkin's lymphoma.
- **Fungicides:** These chemicals can disrupt endocrine functions, leading to hormonal imbalances and reproductive disorders (Serrano-Medina *et al.,* 2019).

2.3 Plant Growth Regulators and Their Health Effects:

Plant growth regulators (PGRs) help control plant growth and enhance crop yields. However, synthetic PGRs can interfere with hormonal balance in humans, potentially affecting fertility and fetal development (Srivastava & Kesavachandran, 2019).

2.3.1 Exposure Pathways and Bioaccumulation:

- **Routes of Exposure**

  Humans come into contact with agrochemicals through multiple pathways:

  - **Occupational Exposure:** Farmers, agricultural workers, and pesticide applicators face direct exposure through handling and inhalation.
  - **Dietary Exposure:** Residues of pesticides and fertilizers in food serve as a primary source of indirect exposure.
  - **Environmental Exposure:** Agrochemicals contaminate air, water, and soil, affecting entire communities, particularly those in agricultural regions (UNEP, 2021).

- **Bioaccumulation and Biomagnification**

  Certain agrochemicals, especially persistent organic pollutants (POPs), do not degrade easily and tend to accumulate in body fat over time (bioaccumulation). As they move up the food chain, their concentration increases, leading to higher toxicity in humans (Katagi & Tanaka, 2016; Wang *et al.,* 2019).

2.4 Health Impacts of Agrochemical Exposure:

The extensive use of agrochemicals, particularly pesticides, has raised serious concerns about their effects on human health. While these chemicals play a crucial role in modern agriculture, prolonged exposure has been linked to severe health issues, including neurological disorders, cancer, hormonal imbalances, and cardiovascular diseases.

- **Neurological Disorders:** Long-term pesticide exposure has been associated with neurodegenerative diseases such as Parkinson's and Alzheimer's (Buralli *et al.,* 2019). These conditions develop gradually as pesticides damage brain cells, leading to memory loss, cognitive decline, and motor dysfunction (Brown *et al.,* 2005). Studies suggest that both genetic predisposition and environmental factors contribute to these disorders, with pesticides playing a role through mechanisms such as oxidative stress and mitochondrial dysfunction (Sherer *et al.,* 2001; Tanner *et al.,* 2011). Even at low doses, certain farming chemicals can subtly impair brain function, increasing the likelihood of dementia-related diseases later in life (Baldi *et al.,* 2003; Hayden *et al.,* 2010).
- **Cancer Risks:** Research has linked pesticide exposure to cancers such as non-Hodgkin's lymphoma, leukemia, and prostate cancer (McDuffie *et al.,* 2001; Pluth *et al.,* 2019). While lifestyle factors like smoking and poor diet are well-known contributors to cancer, involuntary pesticide exposure is an emerging concern (Anand *et al.,* 2008; Stewart, 2012). Some insecticides, including organophosphates and pyrethroids, have demonstrated carcinogenic properties,

particularly with prolonged exposure (Alavanja *et al.,* 2013; George & Shukla, 2011). These chemicals may interact with other environmental toxins or an individual's genetic makeup, increasing cancer susceptibility (Soffritti *et al.,* 2008). Alarmingly, many people are unknowingly exposed to these hazardous substances, unaware of their long-term health risks.

- **Endocrine and Reproductive Disruptions:** Pesticides have been shown to interfere with hormonal balance, affecting fertility in both men and women (Dwivedi *et al.,* 2022). In agricultural regions such as Alto Valle del Río Negro, Argentina, studies indicate that pregnant women living near farms using organophosphate pesticides experience hormonal imbalances, placental complications, and fetal development issues (Bulgaroni *et al.,* 2013; Cecchi *et al.,* 2012). Some pesticides mimic natural hormones, disrupting endocrine functions, while others block essential enzymes required for reproductive health (Usmani *et al.,* 2003; Hernández *et al.,* 2013). Additionally, certain carbamate pesticides have been found to impact thyroid function and interfere with progesterone production (Abreu-Villaça & Levin, 2017). These disruptions can have long-term consequences on fertility, pregnancy outcomes, and overall reproductive well-being.

- **Respiratory and Cardiovascular Diseases:** Inhalation of pesticide aerosols—whether in agricultural fields, manufacturing plants, or contaminated air—can contribute to chronic respiratory conditions and cardiovascular diseases (Berg *et al.,* 2019). Prolonged exposure induces oxidative stress, which can lead to metabolic disorders such as high cholesterol and, ultimately, cardiovascular disease (Reichard *et al.,* 2006; Adeyemi *et al.,* 2021). Studies indicate that workers in pesticide manufacturing industries have a higher prevalence of circulatory system diseases and coronary heart disease (Berg *et al.,* 2019). Scientific findings suggest that pesticide toxicity triggers inflammation and metabolic imbalances, both of which are major contributors to heart disease (Montaigne *et al.,* 2021; Wang & Chen, 2021).

III. CASE STUDIES

- **The Endosulfan Tragedy in India (**Dileep Kumar & Jayakumar, 2019**)**

  Background: Endosulfan, a hazardous pesticide, was used in Kerala's Kasaragod district despite early warnings from 1979.

  Key Events:

  1970s–2001: Aerial spraying by the state-owned Plantation Corporation of Kerala caused widespread health issues (congenital disabilities, cancers).

  2001: A lower court halted the spraying.

  2011: The Supreme Court banned endosulfan nationwide based on the precautionary principle and Article 21 (right to life and health).

  2017: Compensation was awarded to affected victims.

  Impact: The case highlights the critical role of judicial intervention and preventive action in protecting public health and environmental justice.

- **Impact of Glyphosate on Cancer Risk (**Andreotti *et al.,* 2018**)**

  Overview: Glyphosate, a widely used herbicide, was evaluated in a large prospective cohort of 54,251 pesticide applicators from Iowa and North Carolina.

  Exposure & Methods: Exposure was measured as lifetime days and intensity-weighted lifetime days (using self-reported and imputed data). Cancer incidence was tracked through state registries over approximately 15–20 years.

  Key Findings: Overall cancer risk was not increased among glyphosate users. However, applicators in the highest exposure group showed a suggestive (though not consistently statistically significant) increased risk of acute myeloid leukemia (AML), with an observed rate ratio around 2.44.

  Implications: While reassuring for overall cancer incidence, the potential AML risk in high-exposure subgroups calls for continued research and improved exposure controls for applicators.

IV. CONCLUSION

The extensive use of agrochemicals has undeniably boosted agricultural productivity, but the associated health risks are deeply concerning. Incidents such as endosulfan poisoning in India and glyphosate-related lawsuits in the United States highlight the severe consequences of unregulated agrochemical use. The impact extends beyond affected individuals, placing a significant burden on healthcare systems, reducing productivity, and contributing to environmental degradation.

Striking a balance between food security and human health is essential. If the current reliance on agrochemicals continues unchecked, the long-term health repercussions could be devastating. Therefore, immediate action is required to promote sustainable farming practices, enforce stricter regulations, and enhance awareness among both farmers and consumers.

RECOMMENDATIONS

- **Stronger Regulations:** Governments must implement stricter policies to control pesticide and fertilizer use, ensuring that residue levels remain within safe limits.
- **Promotion of Organic Farming:** Encouraging sustainable and organic farming practices can help minimize reliance on harmful agrochemicals.
- **Farmer Education Programs:** Providing farmers with training on safe handling, proper disposal, and eco-friendly pest control methods is essential.
- **Research on Safer Alternatives:** Increased investment in biological pest control, organic fertilizers, and genetically modified pest-resistant crops is crucial for reducing chemical dependency.

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Assessment of Macronutrient Level Variations on the Growth and Morphological Traits of Spinach (*Spinacia oleracea* L.)

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Abstract— *This study investigates the effect of varying levels of macro nutrients on the growth and development of spinach (Spinacia oleracea L.) using a Completely Randomized Design (CRD) with two varieties: Sindhi and English spinach. Conducted during 2024, the experiment utilized a total of six nutrient combinations, including control, NPK (3g/L, 4g/L, 5g/L), and Calcium Nitrate (1g/L), applied to two per pot across replicated treatments. Parameters such as seed germination percentage, germination index, plant height, leaf metrics, root characteristics, and chlorophyll content were assessed. Results indicated a significant enhancement in growth metrics with NPK (3g/L) plus Calcium Nitrate (1g/L), particularly for Sindhi spinach, where it exhibited a germination rate of 95.16% and an increase in chlorophyll to 64.86. Conversely, higher concentrations of NPK negatively affected germination and growth in both varieties, suggesting that balanced nutrient application is crucial for optimal spinach development. This investigation underscores the importance of macro nutrients in enhancing spinach yield, contributing valuable insights for growers aiming to maximize crop productivity.*

Keywords— Spinach, Macro Nutrients, growth, Development.

I. INTRODUCTION

Spinach (Spinacia oleracea L.) is a common leafy green vegetable that belongs to the Chenopodiaceae family. Spinach is a staple leafy green vegetable known for its nutritional value as well as culinary versatility and consumed widely in many countries across the world (Cho et al., 2018). It is believed that this plant originated from southwestern Asia and has been farmed in various parts of Europe, North America, and Australia. Spinach is rich in essential vitamins and minerals, including vitamin A, vitamin C, iron, and calcium. It is low in calories and fat, while high in fiber. So, it can be said that spinach is healthy to consume in any diet (Umar et al., 2007). The ways to eat spinach include raw in salads or cooked with omelets, pastas, and soups. It can also be stuffed into pies and pastries (Max et al., 2016). Spinach has a history dating back to thousands of years ago when people used it for medicinal purposes. It is believed to possess anti-inflammatory and antioxidant properties and may prevent chronic diseases like heart disease and cancer. In short, spinach is a healthy and tasty vegetable enjoyed by many people across the globe for its nutritional benefits and taste (El-Kamony et al., 2000). Spinach is a cool-season annual crop that is often grown from seed. It can be propagated by seeds that are either broad-casted or planted in hills using dry soil (Vignesh et al., 2012). In Egypt, spinach is one of the most important leafy vegetables and has shallow roots, making it relatively easy to grow. Spinach is a very nutritious vegetable with vitamins, minerals, and antioxidants (Ahmadi et al., 2010). It is typically consumed after boiling, either fresh or frozen, or can be eaten raw in salads. Spinach is often used in various dishes, such as omelets, pastas, and soups, and can also be used as a filling for pies and pastries. Major groupings of vegetables are green leafy vegetables, such as spinach, that have been considered to have high nutritional value and health benefits. They are also referred to as "nature's anti-aging wonders" since they can potentially reduce the risk of chronic diseases, such as heart disease and cancer. In addition, spinach has anti-inflammatory properties and may aid in digestion. Spinach is a significant and nutritious vegetable that is consumed globally (Rabie et al., 2014). Spinach is one of the common vegetables grown in most African countries, either for consumption or as a cash crop to generate money. Spinach, like other vegetables, is frequently grown in many parts of Africa, such as in rural, peri-urban, and urban areas (Mdoda et al., 2022). Smallholder farmers often cultivate spinach to increase their food security and income. Spinach is a nutrient-rich and versatile vegetable, which can be consumed in various ways; it can be eaten raw in salads or cooked in dishes like omelets, pastas, and soups. It can also be used as a stuffing for pies and pastries. Spinach has several health benefits like anti-inflammatory and antioxidant activities, thus preventing chronic diseases such as heart disease and cancer. Therefore, spinach is a valuable and delectable vegetable that everyone enjoys across the world (Khalsa, 2003).

II. MATERIALS AND METHODS

The experiment has been conducted during 2024 to Evaluate the Effect of different level of macro nutrient on the development of spinach (Spinacia oleraceae L.), Seeds of two verities were sown in pots (15) containing media soil + silt +FYM in the ratio of 1:1:1 after germination seedling were thinned out and keep two per pot three pots per treatment per verity were maintained for experiment.

2.1 Experimental design: Completely Randomize Design (CRD) – factorial:

Replications: Three (03)

Treatments = Two factors (A & B)

Factor A = micro Nutrients Combinations

N1=Control

N2 =N.P.K (3g L -1)

N3 = Calcium Nitrate (1g L-1)

N4= N.P.K (3g L-1) + Calcium nitrate (1g L-1)

N5= N.P.K (4g L-1) + Calcium nitrate (1g L-1)

N6= N.P.K (5g L-1) + Calcium nitrate (1g L-1)

Factor B = Varieties = 02

V1=Sindhi local

V2 = English

2.2 Data analysis:

We used Statistics 8.1 to perform a statistical analysis of the data (Statistics.2006). We used the LSD (Least Significant Difference) test to compare the treatments when necessary.

III. RESULTS

Present study was carried out in 2024 to investigate the Effect of different level of micro nutrient on the development of spinach (Spinacia oleraceae L.) varieties. The experiment was set up in complete randomized design. Two varieties (Sindhi and English) were treated with different nutrient combinations to check their response on germination and vegetative growth. Observations were recorded on seed germination (%), germination index (GI), Plant height (cm), Leaf length (cm), Leaves plant^{-1}, Leaf weight (g), Leaf width (cm), Fresh biomass of root(g), Root Depth (cm) and Chlorophyll content.

3.1 Seed Germination (%):

Germination index: The germination percentage of spinach varieties was calculated under the impact of different levels of nutrients and the findings are given in Figure 1. The analysis suggested that germination percentage of spinach was significantly influenced by different levels of nutrients ($P<0.05$); and the effect of spinach varieties and interaction results were statistically significant ($P<0.05$). Seed germination (%) has a great influence on early growth and harvesting of crop. The highest germination of Sindhi Spinach seed was achieved when NPK (3g/L) + Calcium Nitrate (1g/L) was applied, with a significantly higher germination value of 95.16% compared to the control. Calcium Nitrate application alone also improved germination with a percentage of 91.23%. This indicates that the positive effect of Calcium Nitrate was noteworthy. Otherwise, an increase in the concentration of NPK in the treatments resulted in low germination in both treatments N5 and N6. The lowest percentage of germination was found at 72.78%. However, for seed of English Spinach, the control group had already achieved a very high germination percentage at 95.87%. Addition of Calcium Nitrate at 1g/L pushed up the germination to 97.47% only, and further addition of NPK at 3g/L + Calcium Nitrate at 1g/L didn't give an increase in germination and remained at 97.47%. As in the case of Sindhi Spinach, the highest concentrations of NPK in the treatments N5 and N6 decreased germination, and the lowest achieved was at 64.87%.

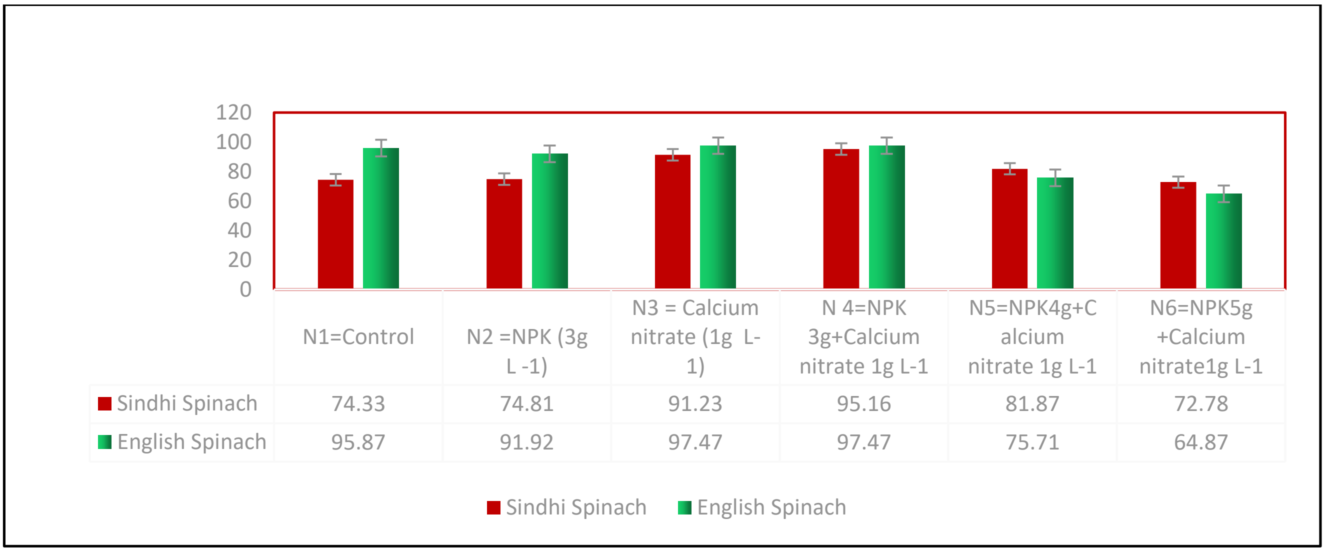
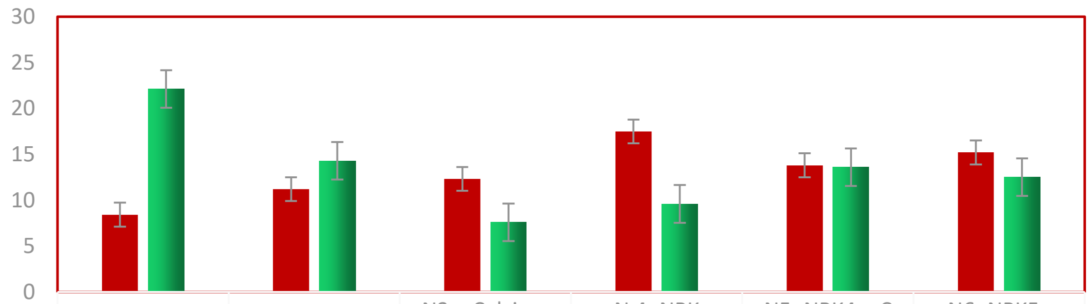


FIGURE 1: Germination % of Spinach Varieties under Nutrient combinations.

3.2 Germination index:

The germination index of spinach varieties was calculated under the impact of different levels of nutrients and the findings are given in Figure 2. The analysis suggested that germination index of spinach was significantly influenced by different levels of nutrients ($P<0.05$). The highest GI was obtained in Sindhi spinach when NPK (3g/L) + Calcium Nitrate (1g/L) was applied, and the value was significantly higher, at 17.51, compared to the control, which had a lower GI of 8.43. The application of Calcium Nitrate (1g/L) alone also showed a positive effect, and the GI value was 12.33, indicating that calcium nitrate plays a beneficial role in enhancing germination for Sindhi spinach. However, when the concentration of NPK was increased in treatments N5 and N6 (NPK 4g/L + Calcium Nitrate 1g/L and NPK 5g/L + Calcium Nitrate 1g/L) whereby the GI decreased slightly. The values reached 13.81 and 15.21 respectively. This means that extremely high concentrations of NPK are not suitable for Sindhi spinach, and an excess amount may cause damage to germination, However, for seed of English spinach, the control group had the highest GI of 22.13, meaning excellent germination under baseline conditions without added nutrients. Addition of NPK at 3g/L led to a decline in GI to 14.3, which indicated that this nutrient combination was less effective for English spinach. Similarly, the treatment with Calcium Nitrate (1g/L) alone resulted in a further reduction of GI to 7.6, which shows that English spinach may not respond well to calcium nitrate supplementation alone. The treatment N4, which was NPK (3g/L) + Calcium Nitrate (1g/L), did not enhance the GI further and resulted in a value of 9.6, which shows a limited response to this combination for English spinach variety. As with the case of Sindhi spinach, the highest values of NPK in treatments N5 and N6 diminished the GI down to 13.61 and 12.52, respectively, indicating an adverse effect on germination because of high NPK concentrations for English spinach as well.



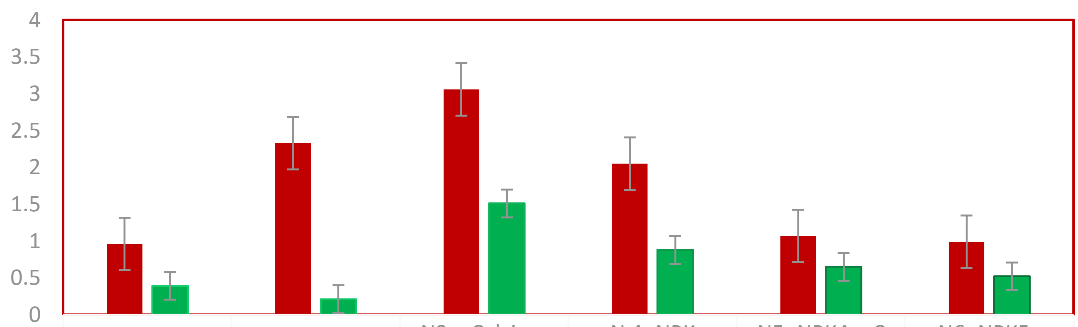
	N1=Control	N2 =NPK (3g L -1)	N3 = Calcium nitrate (1g L-1)	N 4=NPK 3g+Calcium nitrate 1g L-1	N5=NPK4g+Calcium nitrate 1g L-1	N6=NPK5g +Calcium nitrate1g L-1
Sindhi Spinach	8.43	11.2	12.33	17.51	13.81	15.21
English Spinach	22.13	14.3	7.6	9.6	13.61	12.52

■ Sindhi Spinach ■ English Spinach

FIGURE 2: Germination index (GI) of spinach varieties under nutrient combinations

3.3 Plant height (cm):

The Plant height (cm) of spinach varieties was calculated under the impact of different levels of nutrients and the findings are given in Figure 3. The analysis suggested that Plant height (cm) of spinach was significantly influenced by different levels of nutrients ($P<0.05$); and the effect of spinach varieties and interaction results were statistically significant ($P<0.05$). The highest value for plant growth in terms of height was given by Calcium Nitrate (1g/L) (N3), which indicated a height value of 3.06cm. This was significantly higher compared to the control, which received a value of 0.96 cm; this indicates that Calcium Nitrate alone improved Sindhi Spinach growth significantly. Other treatments such as NPK (3g/L) + Calcium Nitrate (1g/L) (N4) and NPK (4g/L) + Calcium Nitrate (1g/L) (N5) resulted in lower plant heights compared to the Calcium Nitrate treatment. Thus, Calcium Nitrate seems to be the best for Sindhi Spinach in terms of height. On the other hand, English Spinach showed a different pattern. While the control with no fertilizer was only 0.39 cm, the best treatment for English Spinach was actually Calcium Nitrate at 1g/L (N3) which produced a height of 1.51 cm. That is better than the control, but significantly lower than the best for Sindhi Spinach variety. Other treatments, including NPK (3g/L) and combinations of NPK and Calcium Nitrate, failed to produce any significant benefits and, in some cases, further reduced the plant height.



	N1=Control	N2 =NPK (3g L -1)	N3 = Calcium nitrate (1g L-1)	N 4=NPK 3g+Calcium nitrate 1g L-1	N5=NPK4g+Calcium nitrate 1g L-1	N6=NPK5g +Calcium nitrate1g L-1
Sindhi Spinach	0.96	2.33	3.06	2.05	1.07	0.99
English Spinach	0.39	0.21	1.51	0.88	0.65	0.52

■ Sindhi Spinach ■ English Spinach

FIGURE 3: Plant Height (cm) of Spinach varieties under nutrients combinations

3.4 Leaf length (cm):

The Leaf length (cm) of spinach varieties was calculated under the impact of different levels of nutrients and the findings are given in Figure 4. The analysis suggested that Leaf length (cm) of spinach was significantly influenced by different levels of nutrients ($P<0.05$); and the effect of spinach varieties and interaction results were statistically significant ($P<0.05$). The leaf growth was observed in Sindhi Spinach to be highest with the combined treatment of NPK (3g/L) and Calcium Nitrate (1g/L), N4 which recorded a length of 8.46 cm of the leaf length. This is a much better compared to the control that had 4.5 cm of the leaf length. This means that NPK and Calcium Nitrate treatment was the best for Sindhi Spinach where there was excellent growth. However, when the concentration of NPK was increased (N5 and N6), the leaf length decreased, which indicated that higher concentrations of NPK were not as beneficial. Overall, the best treatment for Sindhi Spinach was the combination of NPK (3g/L) + Calcium Nitrate (1g/L). On the other hand, English Spinach had a much longer leaf length in the control (12.76 cm) compared to the fertilized treatments. Although the application of Calcium Nitrate (1g/L) (N3) increased the length of the leaf to 6.96 cm, it still remained shorter compared to the control treatment, and treatments with NPK (3g/L) as well as blends with higher levels of NPK had even smaller leaves. There was an apparent optimal performance in the absence of fertilization by English Spinach variety, since the leaf length was lessened in all fertilized treatments compared to the control.

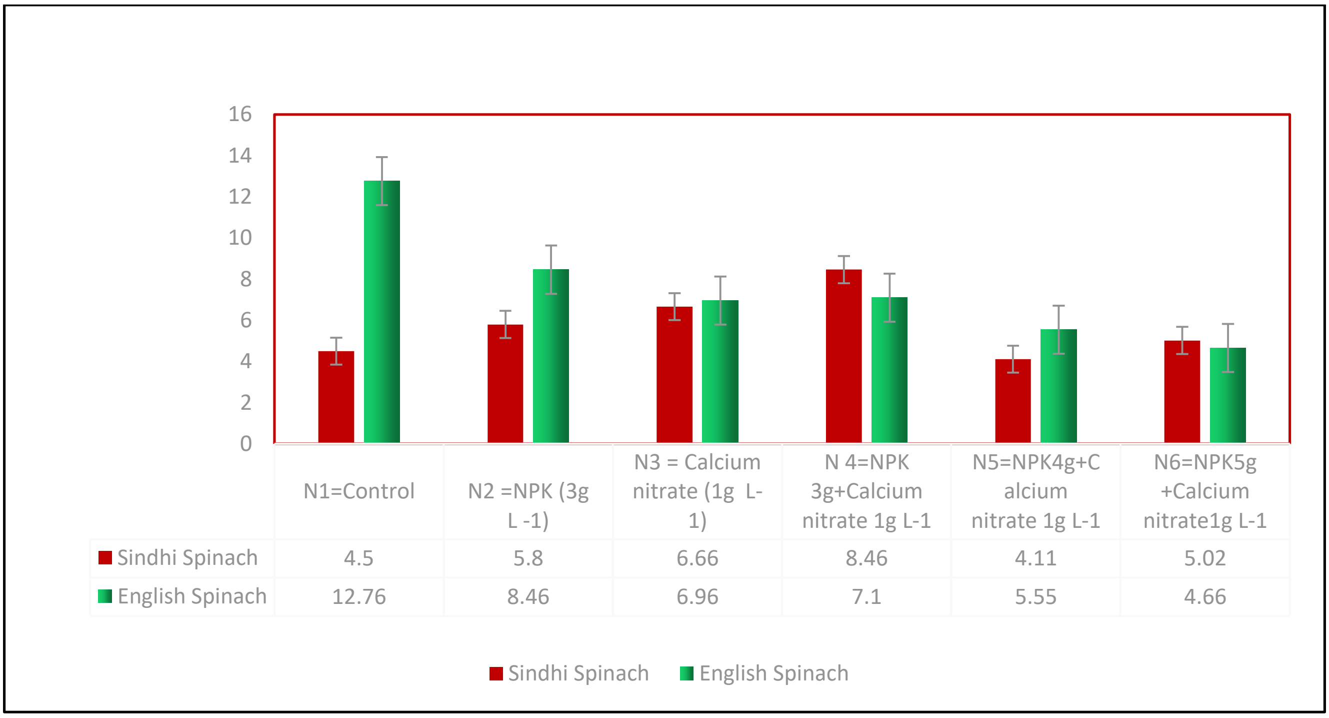


FIGURE 4: Leaf length (cm) of spinach varieties under nutrients combinations

3.5 Leaves plant^{-1}:

The Leaves plant^{-1} of spinach varieties was calculated under the impact of different levels of nutrients and the findings are given in Figure 5. The analysis suggested that Leaves plant^{-1} of spinach was significantly influenced by different levels of nutrients ($P<0.05$); and the effect of spinach varieties and interaction results were statistically significant ($P<0.05$). The control treatment (no fertilizer) yielded 4.33 leaves per plant. The highest increase in leaf number was with the combination of NPK (3g/L) and Calcium Nitrate (1g/L) (N4), where the number of leaves increased significantly to 10. This combination outperformed all other treatments, showing that Sindhi Spinach benefits most from a balanced nutrient mixture. Interestingly, the number of leaves decreased with increasing concentration of NPK, especially in NPK (5g/L) + Calcium Nitrate (1g/L) (N6). This suggests that higher concentrations of NPK may not be as beneficial for Sindhi Spinach. On the other hand, English Spinach had a higher leaf count in the control, which was significantly better than the other fertilized treatments at 8.33 leaves per plant. While the addition of NPK (3g/L) (N2) and NPK (3g/L) + Calcium Nitrate (1g/L) (N4) resulted in 7 leaves, they still did not surpass the control. As with Sindhi Spinach, increasing the concentration of NPK (N5 and N6) caused a decrease in the number of leaves, with the lowest being 4 leaves per plant for both treatments.

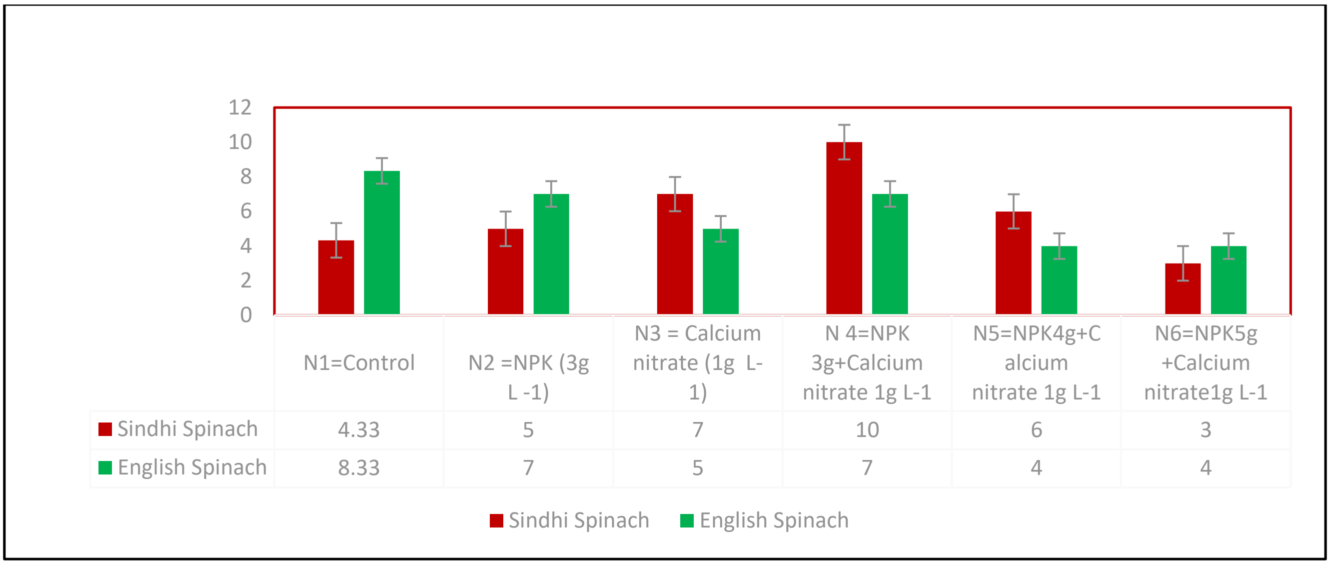


FIGURE 5: Leaves per plant of spinach varieties under nutrient combinations

3.6 Leaf weight (g):

The Leaf weight (g) of spinach varieties was calculated under the impact of different levels of nutrients and the findings are given in Figure 6. The analysis suggested that Leaf weight (g) of spinach was significantly influenced by different levels of nutrients ($P<0.05$); and the effect of spinach varieties and interaction results were statistically significant ($P<0.05$). The control treatment had a low leaf weight, with 6.31 g as compared with some of the fertilized treatments. The increase in leaf weight was most profound when NPK at 3g/L in combination with Calcium Nitrate at 1g/L was given as N4 with a value of 8.46g. This leaf weight was the highest compared to that of the control. This implies that Sindhi Spinach reacted to this nutrient mix best by achieving maximum increase in the leaf weight. However, increasing the NPK concentrations further at N5 and N6 results will decline the leaf weight, implying that at these higher NPK levels, there was no gain in the leaf growth. In contrast, with regard to English Spinach, a different trend will be presented. The control treatment produced a leaf weight of 13.95 g that was much greater than that produced by Sindhi Spinach. It means that the leaf weight in English Spinach is greater by nature compared to Sindhi Spinach without applying any nutrient supplement. Applying NPK at the rate of 3g/L or Calcium Nitrate at the rate of 1g/L (N2 and N3) reduced the leaf weight with the reduction up to 10.73 g and 9.28 g, respectively. The additive effect of NPK (3g/L) + Calcium Nitrate (1g/L) (N4) showed a slight increase to 8.79 g but was still not as high as the control. The increased concentration of NPK led the leaf weight to continue in decline, and the minimum value was recorded in the treatment NPK (5g/L) + Calcium Nitrate (1g/L) (N6), at a value of 6.66 g.

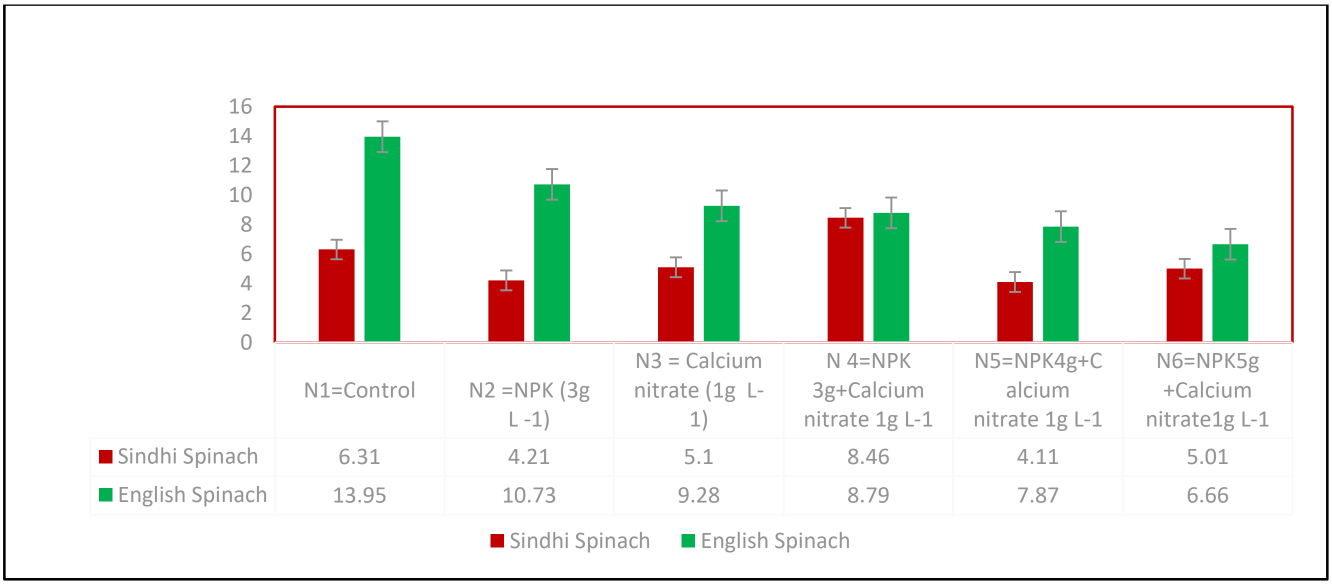


FIGURE 6: Leaf weight (g) of spinach varieties under nutrients combinations

3.7 Leaf width (cm):

The Leaf width (cm) of spinach varieties was calculated under the impact of different levels of nutrients and the findings are given in Figure 7. The effect of spinach varieties and interaction results were statistically significant ($P<0.05$). The control treatment without fertilizer resulted in a leaf width of 3.21 cm. The addition of Calcium Nitrate at 1g/L increased the leaf width to 3.8 cm with a positive response. The highest improvement was found with the addition of NPK at 3g/L along with Calcium Nitrate at 1g/L (N4), where the leaf width increased to 6.46 cm, which was a huge improvement over the control. This combination of nutrients proved to be the most effective in promoting leaf width in Sindhi Spinash. Interestingly, with an increase in the concentration of NPK (N5 and N6), the leaf width decreased, with the lowest being 2.3 cm for NPK (4g/L) + Calcium Nitrate (1g/L) (N5), suggesting that excessive NPK was harmful to the leaf width in Sindhi variety. In contrast, English Spinach had a larger leaf width in the control (5.6 cm) than Sindhi Spinach. However, the addition of NPK (3g/L) (N2) reduced the leaf width slightly to 5.06 cm, and Calcium Nitrate (1g/L) (N3) further decreased it to 4.36 cm. The smallest leaf width was 3.16 cm, significantly lower than the control, with the combination of NPK (3g/L) + Calcium Nitrate (1g/L) (N4). This nutrient combination was not favorable for English Spinach. With the increase in the concentration of NPK (N5 and N6), the leaf width decreased further, with the lowest being 2.16 cm for NPK (4g/L) + Calcium Nitrate (1g/L) (N5).

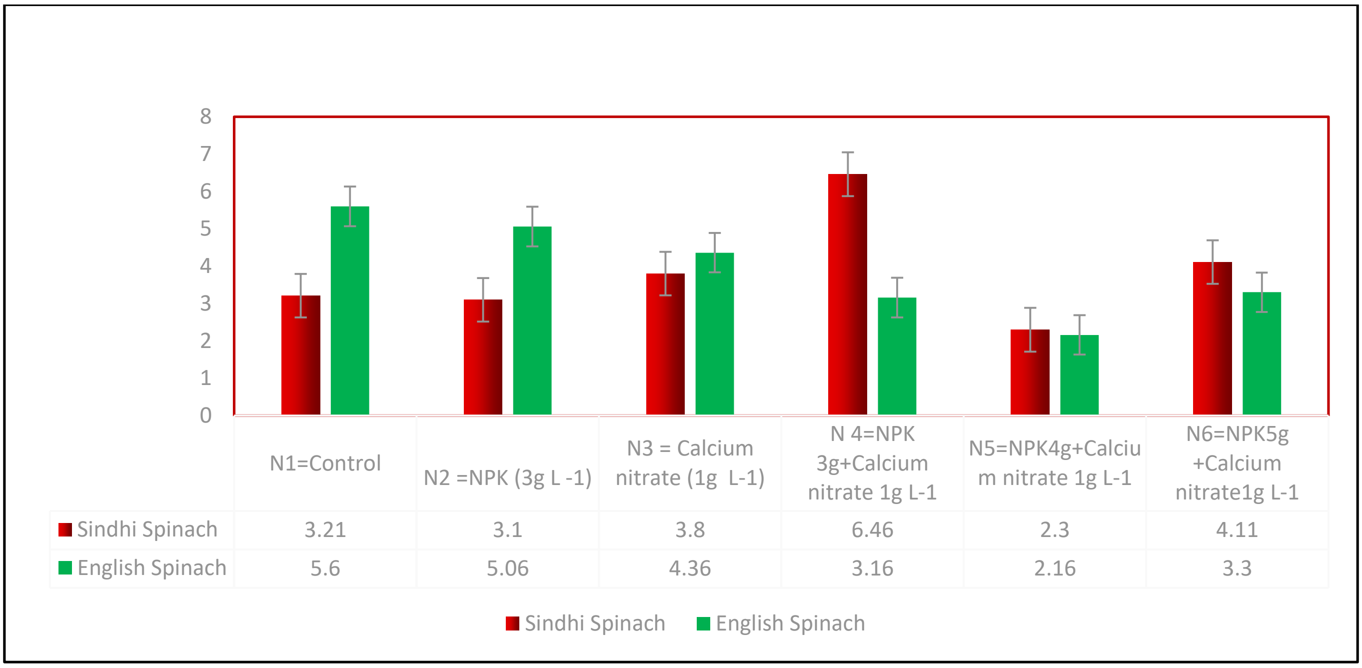


FIGURE 7: Leaf width (cm) of Spinach varieties under nutrients combinations

3.8 Fresh biomass of root (g):

The Fresh biomass of root (g) of spinach varieties was calculated under the impact of different levels of nutrients and the findings are given in Figure 8. The analysis of variance (ANOVA) suggested that Fresh biomass of root (g) of spinach was significantly influenced by different levels of nutrients ($P<0.05$); and the effect of spinach varieties and interaction results were statistically significant ($P<0.05$). The control (N1) treatment resulted in a root biomass of 0.38 g from Sindhi Spinach, which was relatively low. The addition of NPK (3g/L) (N2) caused a significant increase to 0.66 g, making it the best treatment for promoting root biomass in Sindhi Spinach. Even the combination of NPK (3g/L) + Calcium Nitrate (1g/L) (N4), which produced a root biomass of 0.64 g, performed well compared to the control. However, an increase in the concentration of NPK (N5 and N6) resulted in a reduction in root biomass at 0.43 g and 0.45 g, respectively, which indicated that higher doses of NPK were not beneficial for root growth in Sindhi Spinach. For English Spinach, the control produced the highest root biomass at 0.77 g, which was significantly higher than that of Sindhi Spinach in the control. Fertilization generally did not improve root biomass in English Spinach. For instance, NPK (3g/L) (N2) resulted in 0.73 g, a slight decrease, and Calcium Nitrate (1g/L) (N3) led to 0.54 g, further lowering the root biomass. The NPK (3g/L) + Calcium Nitrate (1g/L) (N4) produced 0.69 g, which is still lower than the control. Even at higher concentrations of NPK (N5 and N6), the root biomass was not higher than the control at 0.45 g and 0.63 g, respectively.

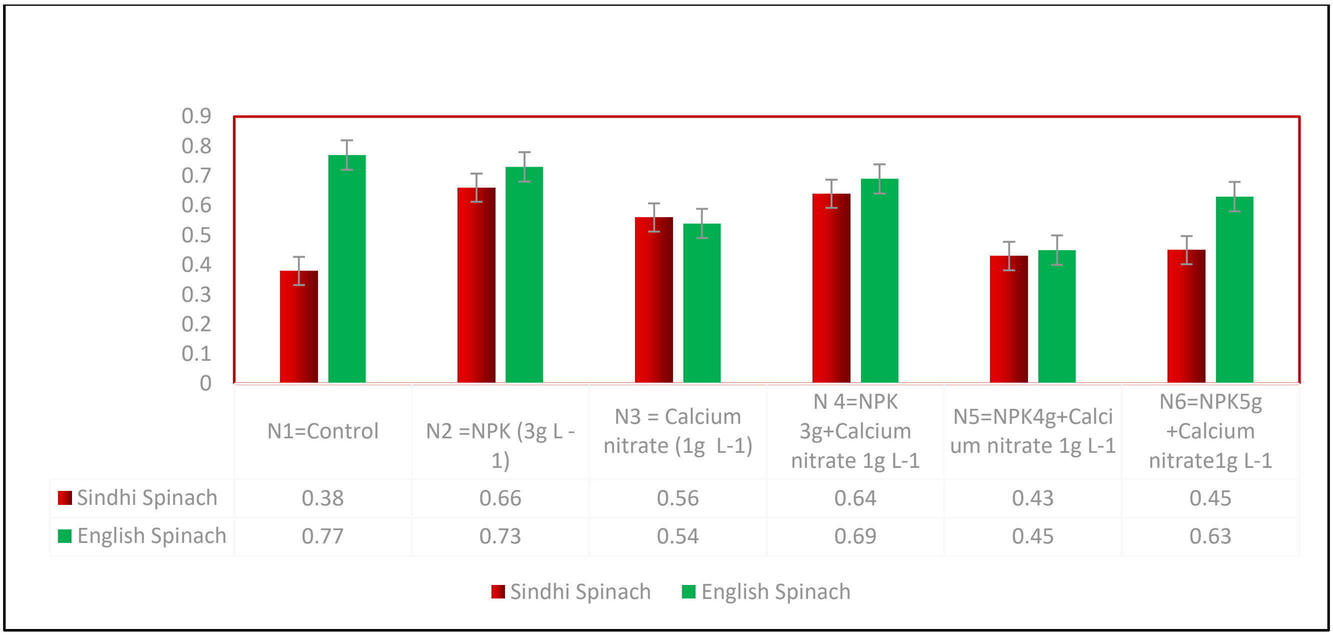


FIGURE 8: Fresh biomass of root(g) of spinach varieties under nutrients combinations

3.9 Root Depth (cm):

The Root Depth (cm) of spinach varieties was calculated under the impact of different levels of nutrients and the findings are given in Figure 9. The analysis suggested that Root Depth (cm) of spinach was significantly influenced by different levels of nutrients ($P<0.05$); and the effect of spinach varieties and interaction results were statistically significant ($P<0.05$). The control (N1) resulted in a root depth of 11 cm of Sindhi Spinach. The root depth increased slightly with the addition of NPK (3g/L) (N2) to 11.74 cm and further with Calcium Nitrate (1g/L) (N3) to 13.06 cm. However, the highest increase in root depth was with the combination of NPK (3g/L) + Calcium Nitrate (1g/L) (N4), which showed a very significant increase in root depth to 20.46 cm, much deeper than in the control. Higher concentrations of NPK at N5 and N6 recorded slight decreases of root depth: 11.02 cm, and 14.46 cm, respectively, which may indicate a limitation of using excessive NPK for root deepening in Sindhi Spinach. On the other hand, English Spinach had its deeper root compared to Sindhi Spinach that was recorded from the control with a root depth of 17.43 cm. However, with the application of NPK (3g/L) (N2), the root depth was reduced to 13 cm. The addition of Calcium Nitrate (1g/L) (N3) resulted in a slight increase to 13.36 cm. The combination of NPK (3g/L) + Calcium Nitrate (1g/L) (N4) led to a modest reduction in root depth to 16.1 cm, which was still greater than the control. With increasing NPK concentration, the depth of the root was further decreased with 15.1 cm and 14.46 cm, respectively at N5 and N6.

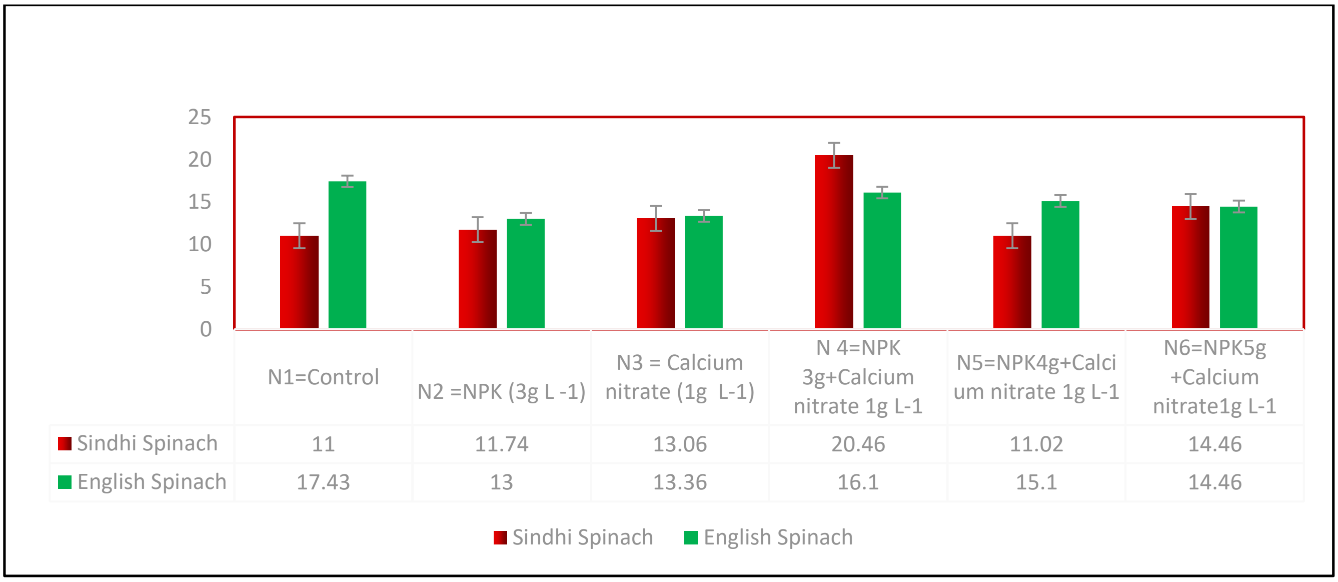


FIGURE 9: Root Depth (cm) of spinach varieties under nutrient combinations

3.10 Chlorophyll content (SPAD):

The Chlorophyll content (SPAD) of spinach varieties was calculated under the impact of different levels of nutrients and the findings are given in Figure 10. The effect of spinach varieties and interaction results were statistically significant ($P<0.05$).

The control treatment was 28.1 from the Sindhi Spinach, very low. NPK at 3g/L had a little better result, and that was about 34.06. The treatment with Calcium Nitrate at 1g/L had the most dramatic improvement, as the chlorophyll level reached 64.86, far beyond the control and other treatments. This indicates that in using Calcium Nitrate, the plants have been more amplified for chlorophyll enhancement in Sindhi Spinach. While the combination of NPK (3g/L) + Calcium Nitrate (1g/L) increased to 35.8, it was lower than the boost seen with Calcium Nitrate alone. Other treatments like NPK (4g/L) + Calcium Nitrate (1g/L) and NPK (5g/L) + Calcium Nitrate (1g/L) also increased the chlorophyll content to 57.43 and 42.63, respectively, but these were still lower than the Calcium Nitrate treatment alone. The control treatment for English Spinach showed a chlorophyll content of 27.43, slightly lower than the control of Sindhi Spinach. The NPK (3g/L) treatment caused an abrupt increase to 54.41, and thus NPK alone was found to be very effective for raising the chlorophyll content of English Spinach. However, when Calcium Nitrate (1g/L) was applied, the chlorophyll content decreased to 33.36, which indicates that Calcium Nitrate was not as beneficial for English Spinach as it was for Sindhi Spinach. The combination of NPK (3g/L) + Calcium Nitrate (1g/L) led to a chlorophyll content of 46.1, which was an improvement over the control but still not as high as the response to NPK (3g/L) alone. The other treatments of higher NPK concentrations produced the following; namely, N5 and N6, gave results of 35.1 and 44.46 respectively lower than NPK (3g/L) treatment.

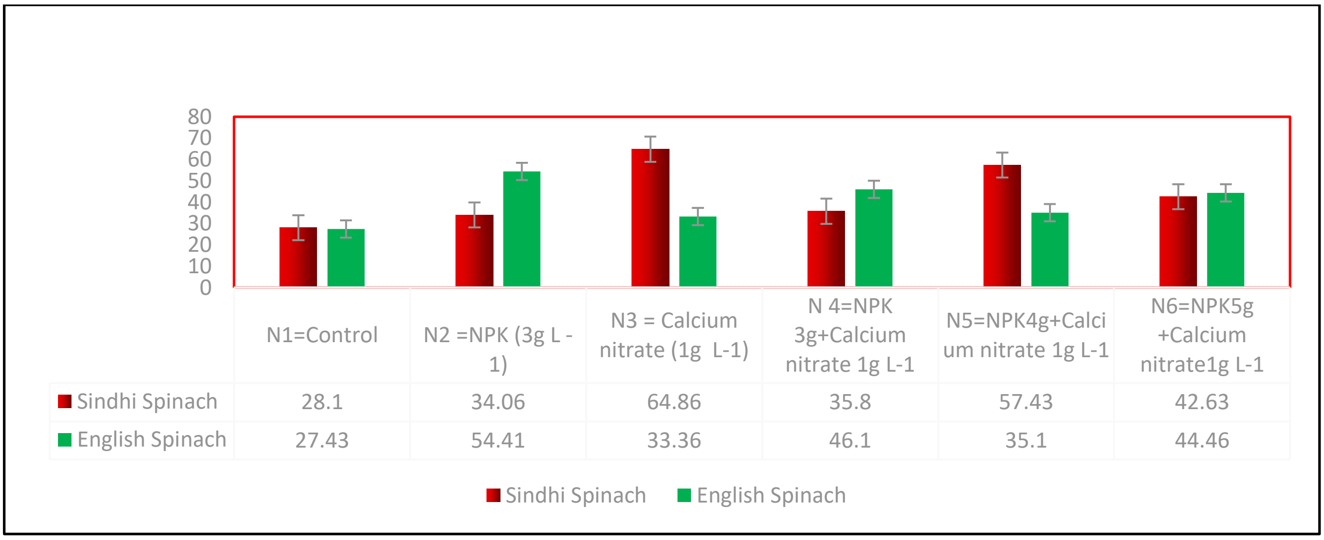


FIGURE 10: Chlorophyll content (SPAD) of spinach varieties under nutrient combinations

IV. DISCUSSION

The macro nutrients have been used to enhance of vegetables and fruiting behaving of horticultural crops. These macro and micro nutrients have triggered various physiological characteristics and plants. The leaves of green factories where photosynthesis produces compounds needed for growth. These are absorbed right at the site they are used acting fast. The study established that crop yield in spinach is enhanced when macro nutrients were applied combined rather than used separately. NPK and calcium nitrate will provide maximum net return to growers (Ali at al., 2024). In this present study the effect of nutrient on production of spinach was tried by using the commercial product named as NPK which was a powder containing diverse essentially needed macro nutrients. NPK was applied at the concentration of NPK 3g L^{-1} and calcium nitrate 1g L^{1} and control was maintained to check the plants performance. Maximum result in spinach were obtained under NPK 3g L^{1} + calcium nitrate 1g L^{1}. It produces most of the observed parameters in a maximum value as compared to other treatment. A significant amount of research work has been reported from different parts of the world on the aspect under the study. The result of the present investigation are in concurrence with the result of (Abgad at al., 2015) used a compound powder form fertilizer containing most macro nutrients along with NPK and calcium nitrate these fertilizers provide nutrients to the plant these fertilizers are completely soluble in water. Further, our results are in accordance with the finding of (Robinson, D. (1994) which found maximum plant height (14.78 cm), leaves plant^{1} (7.50), leaf length (7.63) determined the effect of fertilizer of NPK (20-20-20+TE) and calcium nutrient and concluded that plant yield and total uptake of nutrient by plant varied significantly with respect to plant population and nutrient levels.

A comparative analysis of the findings of the present study and findings of past workers indicated that there is great scope for improving the yield of spinach through NPK and calcium nitrate of macro nutrients.

V. CONCLUSION

The Present study showed the significant influence of NPK and calcium nitrate on spinach growth. NPK (3g/L) and calcium nitrate (1g/L) positively impacted seed germination, plant height, leaf metrics, root characteristics, and chlorophyll content, especially for Sindhi spinach. Higher NPK concentrations negatively affected germination and growth in both varieties, highlighting the importance of balanced nutrient application for optimal spinach development. These findings offer valuable insights for maximizing crop productivity and emphasize the significance of macro nutrients in enhancing spinach yield.

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An acknowledgement section may be presented after the conclusion, if desired.

AUTHORS' CONTRIBUTIONS

MRM and MAW: Conceived and designed the study, and prepared the initial draft of the manuscript. MRM, MAW, MAJ: Carried out the experimental work and collected the data. GHW: Provided technical guidance, assisted in data analysis, and contributed significantly to manuscript refinement. LQ: Offered continuous technical support throughout the research process. IAJ and FHC: Assisted in data organization, tabulation, and preliminary compilation. FAJ and FHC: Contributed to statistical analysis and graphical data representation. KHC and KAM: Provided input on experimental layout and contributed to manuscript writing. AQK and ARS: Critically reviewed and revised the manuscript for intellectual content.

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Effect of Sulphur, Goat Manures and Intercropping on Morphophysiological and Yield Performance of Sesame (*Sesamum indicum* L.)

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***Abstract*— *A field experiment was conducted in Kharif season of 2024–2025 at the Agricultural Research Farm, Department of Agronomy, Himalayan University, Jollang, Itanagar, Arunachal Pradesh. The soil of experimental plot was sandy loam and loamy sandy in texture with pH ranges from 4 to 6. The experiment was laid out in a Randomized Block Design (RBD) with seven treatments each replicated thrice three. The treatments which are T_1: Control, T_2: Sulphur level 40kg/ha + Goat Manure 14 ton/ha.+ intercropping (2:1), T_3: Sulphur level 40kg/ha + Goat Manure 14 ton/ha. +intercropping (2:2), T_4: Sulphur level 40kg/ha.+ Goat Manure 15 ton/ha.+ Intercropping (2:1), T_5: Sulphur level 40kg/ha. + Goat Manure 15 ton/ha + intercropping (2:2), T_6: Sulphur level 40kg/ha + Goat Manure 16 ton/ha + intercropping (2:1), T_7: Sulphur level 40kg/ha. + Goat Manure 16 ton/ha.+ Intercropping (2:2). The results showed maximum morphological of plant height (103cm), number of branches (7.90), dry weight (19.40) were recorded significantly higher in the treatment T_7 which is Sulphur level 40kg/ha. + Goat Manure 16 ton/ha.+Intercropping (2:2).The Physiological and yield attributes the maximum number of capsule/plant (81.00), capsule length (3cm), seeds/capsule (78.53), test weight (3.37g), seed yield (0.46t/ha), biological yield (0.398t/ha), harvest index (1.01%) were recorded in the treatment T_7 as compared to all other treatments.*

***Keywords*— Sesame, Sulphur, Goat manure, Intercropping, Morph-physiological traits and yield.**

I. INTRODUCTION

Sesame (*Sesamum indicum L.*) family of ***pedaliaceae***, Sesame or gingelli is commonly known as til, is one of the oldest cultivated oilseed crops, known for its resilient growth in arid conditions and highly valued seeds for their oil and nutritional content. Sesame is considered as a drought tolerant crop. Often hailed as the “Queen of Oilseeds”, it owes this distinction to its remarkably high oil content, which can reach to 63%, surpassing the quality of other oilseed crops such as groundnut (45%–56%), sunflower (45%), rapeseed (40%), and soybean (20%) (Teklu *et al*., 2021). The oilseeds are very important because of its capability of synthesis of sulphur containing amino acids, vitamins, and constituent in human dietary system next to carbohydrates, protein and fats (Mohsana, 2009). Sesame seed cake contains 32% crude protein and 8–10% oil, making it an essential feed for livestock, poultry, and small ruminants (Kabinda *et al.*, 2022). To address these issues, improving seed quality, optimizing sowing times, applying recommended fertilizer dosages, and implementing effective pest management strategies can help increase sesame productivity and profitability for farmers.

Intercropping, the practice of growing two or more crops in proximity, is a promising strategy for enhancing sesame (Sesamum indicum) production. Research by **Ghosh *et al.*, (2004)** highlights its potential to optimize land use, boost biodiversity, and improve soil health. Intercropping sesame with legumes like cowpeas can enhance soil fertility through nitrogen fixation, as noted by **Khan *et al.*, (2017).** Additionally, diverse cropping systems can disrupt pest life cycles, contributing to sustainable pest management, a finding supported by (**Pérez *et al.*, (2019).** Intercropping is the practice of growing more than one crop simultaneously in alternating rows of the same field (Beets 1990).

Sulphur play a key role in plant metabolism, indispensable for the synthesis of essential oils, chlorophyll formation, required for development of cells and it also increase cold resistance and drought hardiness of crops especially for oil seeds crops (Patel *et al.*, 1995). In oilseeds, Sulphur plays significantly increasing the yield and oil content of sesame (Deshmukh *et al.*, 2010) and helps in improving quality and boldness in seeds. Therefore, oilseed crops require large amount of sulphur for better development and growth to obtain higher yield (Salwa *et al.*, 2010).

Sulphur deficiency is becoming more critical with each passing year which is severely restricting crop yield, produce quality and nutrient use efficiency. Sulphur, therefore, is now very much a part of balanced fertilization because in S deficient areas. Its deficiency results in reduced plant height and stunted growth, impairs tillering capacity and delayed maturity. Sulfur deficient plants have also less resistance under stress conditions (Dobermann 2000). Sulphur application not only improved the grain yield but also improved the quality of crops. (Kathiresan 2002).

Among several types of organic manures, goat manure is significantly known for high level of potassium which is a major component of ash and also potentially require for protein synthesis. N, P, K, Ca, Mg, pH, growth and yield parameters increase with the application of goat manure. (Barlow & Curran (2015). It not only improves soil conditions but also enhances the growth of sesame. Goat manure is rich in essential macronutrients, including nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sulfur (S), which are critical for plant health (Hartatik and Widowati, 2006).Goat manure is a new technique that doesn't hurt the environment and can allow nutrient-rich organic soil fertilizer development. Goat manure is reported to contain enough nutrients to meet the needs of plants for optimal growth. It is still shameful that manure is not usually put on agricultural land in Sub-Saharan African (SSA) nations (Washaya *et al*., 2023).

II. MATERIALS AND METHODS

The experimental trial was carried out during kharif 2024 at Agriculture research farm of Himalayan University. The agriculture Research Farm is situated at 27.14ºN latitude and 93.62º E longitudes. The location of jollang was tropical climate zone with an average rainfall of 3500-4000mm at an average meters from mean sea level. The soil of experimental plot was sandy loam and loamy sandy in texture with pH ranges from 4 to 6. The recommended dose of NPK: 20:20:30 and sulphur was applied according the treatment details. After sowing gap filling was done and there was no need of irrigation due to frequent rainfalls. Between the period of germination to harvest several plant growth parameters was recorded at equal intervals and after harvest yield parameters were recorded. In growth parameters plant height (cm), plant dry weight (g) and number of branches/plant were recorded and yield parameters like capsules/plant, seeds/capsule, Test weight (1000 seed weight), seed yield t/ha) Biological yield (t/ha) and harvest index %) were recorded and statisticall analyzed using analysis of variance (ANOVA) as applicable to Randomized Block Design.

III. RESULTS AND DISCUSSION

3.1 The statistical data regarding morphophysiological parameters is presented in Table no:1:

3.1.1 Plant height (cm):

Significantly highest plant height (103.00cm) was observed in treatment T_7 (Sulphur level 40kg/ha. + Goat Manure 16 ton/ha.+ Intercropping (2:2)and followed by T_2 (Sulphur level 40kg/ha + Goat Manure 14 ton/ha.+ intercropping (2:1) i.e., (98.67cm). Lowest plant height (10.20cm) was noted in T_1, Control. This might be due to different application of organic manures and micronutrients from goat manure and sulphur and nutrient utilization through intercropping which increase the plants and enhances the vegetative growth of the plant thus, leading to significant increase in plant height. These findings corroborate with the results obtained by Tiwari *et al*., (2000) Aripta *et al*., (2015), Aripta *et al*. , (2018), Singarvel *et al.*, (2019). Sujatha *et al*., (2021).

3.1.2 Number of branches plant^{-1}:

Significantly highest no. of branches^{-1} (7.90) was recorded in the T_7 (Sulphur level 40kg/ha. + Goat Manure 16 ton/ha.+ Intercropping (2:2) and followed by T_2 (Sulphur level 40kg/ha + Goat Manure 14 ton/ha.+ intercropping (2:1) i.e., (7.80) and lowest number of branches (3.33) was noted in T_1 Control. The increase in branching may be due to sulphur which helps in stimulation of cell division and photosynthetic process as well as chlorophyll and better growth conditons under intercropping. Application of sulphur might be the reason that is causes improvement in soil properties and hence nutrients availability to the crop during vegetative growth and development period of plant.These results were accordance with those of Srinivasan and Sankaran (2001), Aripta *et al.*, (2018) Swapan Kumar *et al.*, (2019) Aripta *et al.*, (2021), Kumar *et al.*, *(*2017), Sujatha *et al*., (2021). Nadeem *et al.*, (2015).

TABLE 1
EFFECT OF SULPHUR, GOAT MANURES AND INTERCROPPING ON MORPHOPHYSIOLOGICAL PARAMETERS OF SESAME

Treatments	Plant height(cm)	Dry weight^{-1}(g)	No. of branches plant^{-1}
T_1	80.00	10.67	3.33
T_2	98.67	19.33	7.80
T_3	97.33	16.07	7.70
T_4	92.67	14.07	5.00
T_5	95.33	16.00	7.00
T_6	95.00	15.73	6.00
T_7	103.00	19.40	7.90
SEd	4.18	0.37	0.53
SEm(±)	2.95	0.26	0.37
CD	9.10	0.82	1.16

3.1.3 Dry weight^{-1} (g):

Data recorded maximum dry weight (33.47g) was recorded in treatment T_7 Sulphur level 40kg/ha. + Goat Manure 16 ton/ha.+ Intercropping (2:2) and followed by T_2 (Sulphur level 40kg/Ha + Goat Manure 14 ton/ha.+ intercropping (2:1) i.e., (33.43g).Lowes dry weight (23, 30g) was observed in treatment T_1 (Control). It has been reported that the Sulphur application not only improves the availability itself but also improves availability of other nutrients too, which are essential for growth and development of plant. The improved of dry weight under T_7 may be attributed to enhanced the availability and better resource It has been also reported that Sulphur helps in reducing soil pH, which helps in the greater availability and mobility of nutrients especially P, Fe, Mn, and Zn. Aripta *et al.* , (2015), Aripta *et al.* , (2018) Aripta *et al.*, (2021) Kumar *et al.* (2012), (Hilal *et al.*, 1992).

3.2 The statistical data representing yield and yield attributes presented in Table no. 2:

3.2.1 No. of capsule plant^{-1}:

Data recorded on number of capsule plant^{-1} was statiscally analysed and maximum number of capsule plant^{-1} was (81.00) recorded under treatment T_7 (Sulphur level 40kg/ha. + Goat Manure 16 ton/ha.+ Intercropping (2:2) and followed by T_2 (80.44) under treatment T_2 (Sulphur level 40kg/ha. + Goat Manure 16 ton/ha.+ Intercropping (2:1) and minimum number of capsule plant^{-1} (70.33) was noted in T_1, Control. This is due to different application of goat manure which allow nutrient- rich in essential macronutrients and enhances the vegetative growth of the plant thus, leading to significant increase in number of capsule per plant.Hartatik *et al.*, (2006) Ojeniyi *et al.*, *(*2010) B.Arpita *et al*., (2015).

3.2.2 No. of seed capsule^{-1}:

Significantly maximum number of seed per capsule (78.53) was recorded in treatment T_7 Sulphur level 40kg/ha. + Goat Manure 16 ton/ha.+ Intercropping (2:2) and followed by T_2 (Sulphur level 40kg/Ha + Goat Manure 14 ton/ha.+ intercropping (2:1) i.e., (65.77).Lowest number of seed per capsule (38.60) was observed in treatment T_1 (Control). The increased seed number in T_7 is due to goat manure improves the seed quality which increase the plants and enhances reproductive development, and intercropping which promote efficient nutrient use and better pollination leads to significant increase in number of capsule per plant. Hartatik *et al.*, (2006), B.Arpita *et al*., (2015).

3.2.3 Capsule Length (cm):

Data recorded on capsule length (cm) revealed that maximum (3.2cm) capsule length was observed in the T_7 (Sulphur level 40kg/ha. + Goat Manure 16 ton/ha.+ Intercropping (2:2)) and closely followed by T_2 (3.1cm) (Sulphur level 40kg/ha. + Goat Manure 16 ton/ha.+ Intercropping (2:1). Whereas minimum capsule length (2.8cm) was noted in T_1, Control. The improvement in T_7 may be due to Sulphur, goat manure which play energetic role in nutrition of plants and it also improved the quality of seeds. (Adeyemo *et al.,* (2019); Sharma *et al*., (2020); Ogunyemi *et al*., (2018).

TABLE 2
EFFECT OF SULPHUR, GOAT MANURES AND INTERCROPPING ON YIELD AND YIELD ATTRIBUTES OF SESAME

Treatments	No. of capsule plant^{-1}	No. of seed capsule^{-1}	Capsule length(cm)	Test weight(g)	Seed/Economic yield(t/ha)	Biological yield(t/ha)	Harvest index(%)
T_1	70.33	38.60	2.8	2.80	0.22	0.378	0.58
T_2	80.44	65.77	3.1	3.30	0.38	0.397	0.95
T_3	80.33	66.00	3.1	3.27	0.36	0.394	0.91
T_4	74.44	60.67	2.3	2.93	0.31	0.393	0.78
T_5	78.55	62.60	3.0	3.23	0.36	0.393	0.91
T_6	76.00	63.10	3	3.07	0.34	0.391	0.86
T_7	81.00	78.53	3.2	3.37	0.46	0.398	10.1
SEd	1.03	2.63	0.17	0.11	0.01	1.81	0.00
S.Em (±)	0.72	1.86	0.12	0.07	0.00	1.28	0.00
CD	2.24	5.74	0.38	0.23	0.02	3.95	0.01

3.2.4 Test weight (g):

Data recorded on the test weight of sesame seed was statistically analyzed and presented in Table-3. The effect of different treatments were found to be significant in case of test weight of sesame. The highest (3.37g) test weight of sesame was under treatment T_7 (Sulphur level 40kg/ha. + Goat Manure 16 ton/ha.+ Intercropping (2:2) and followed by T_2 i.e., 3.30g.The lowest number (2.80g) of test weight was recorded at T_1 (Control). Which is due to application goat manure and sulphur and intercropping (green gram + sesame) which improves nutrient availability and assimilation during seed filling which enhanced the better crop synergy through intercropping. Olowe *et al.,* (2003) Nadeem *et al*., (2015) Aripta *et al*., (2015) Kumar *et al.* (2012).

3.2.5 Seed yield (t/ha^{-1}):

Significantly maximum seed yield (0.46/ha) was recorded in treatment T_7 (Sulphur level 40kg/ha. + Goat Manure 16 ton/ha.+ Intercropping (2:2) and followed by T_2 i.e., 0.38t/ha. The lowest number of seed yield was recorded at T_1 (control) i.e., 0.22t/ha. These is due to application of Goat manure and sulphur and intercropping (green gram + sesame) sulphur played important role in improving yield attributes an increase yield seed yield. Which together promote better seed development and harvest output. A.R.F Suaad *et al*., (2025) Washaya *et al*., (2023) Sujatha *et al., (*2021) Oloniruha *et al*., (2021) Myini *et al*., (2020) Vekeriya *et al*., (2020).

3.2.6 Biological/ Stover yield (t/ha):

Data recorded on biological yield of sesame was statistically analyzed and highest biological yield was recorded in T_7 (Sulphur level 40kg/ha. + Goat Manure 16 ton/ha.+ Intercropping (2:2) i.e., 0.398 t/ha^{-1}.The lowest biological yield was recorded in T_1 control i.e., o.378 t ha^{-1}. The increase in T_7 can be linked to better plant growth and seed yield due to the combined effect of slow- release of sulphur and goat manure and improved resource utilization in the intercropping system. Haruna *et al*., (2012) Kundu C.K *et al*., (2014) Nadeem *et al.*, (2015).

3.2.7 Harvest index (%)

The significant and highest harvest index (10.1%) was recorded in T_7 (Sulphur 40kg/ha. + Goat Manure 16 ton/ha.+ Intercropping (2:2).The lowest harvest index (0.58%) was recorded in T_1 control. The higher harvest index in T_7 suggests better partitioning of assimilates towards economic yield and lower value may be T_2 is due to greater vegetative biomass reducing the proportion of economic yield. Sharma *et al*.,(2020), Kumar *et al.* (2012) Nadeem *et al*.,(2015).

IV. CONCLUSION

Based on the findings of the investigation it may be concluded that T_7 (Sulphur level 40kg/ha. + Goat Manure 16 ton/ha.+ Intercropping (2:2) performed expecptionally in all growth and yield parameters and in obtaining maximum seed yield of sesame. Hence, (Sulphur level 40kg/ha. + Goat Manure 16 ton/ha.+ Intercropping (2:2) is beneficial for future use.

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Impact of Vermicompost and Intercropping on Morphophysiological and Yield Performance of Sesame (*Sesamum indicum* L.)

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***Abstract*—** *A field experiment was conducted at the Agricultural Farm, Himalayan University, Jollang, to investigate the Impact of Vermicompost and Intercropping on the Morphophysiological and Yield Performance of Sesame (Sesamum indicum L.).*

The study was laid out in a Randomized Block Design (RBD) with seven treatments replicated thrice. Sesame variety INDO US-5 and green gram variety KANIKA were evaluated at 30, 60, and 90 days after sowing (DAS). Among the treatments, T7 (100% RDF + Vermicompost 6 t/ha + Intercropping 2:2) consistently recorded superior results in terms of plant height (84.3 cm), number of leaves (67.6), number of branches (5.0), were observed during 60–90 DAS in T7. Moreover, T7 showed significant improvement in yield attributes such as capsule number (45.6), seed per capsule (38.6), capsule length (3.6 cm), test weight (3.7 g), biological yield (1.22 t/ha), and economic yield (0.46 t/ha). The highest harvest index (37.50%), were also recorded in T7. These results highlight the potential of integrated nutrient management and intercropping in enhancing sesame productivity and profitability.

Keywords*— *Sesame, Vermicompost, Intercropping, Organic manure, physiological traits, Agronomic traits.

I. INTRODUCTION

The scientific name of sesame is (*Sesamum indicum* L) belongs to the family of Pedaliaceae. Sesame is commonly known as till, simsim, beniseed etc. sesame is an oilseed plant therefore it has been used as oil since ages. Sesame crop's oil consists of 85% unsaturated fatty acid, is highly stable, reduces cholesterol, and prevents coronary heart diseases (Choudhary *et al*., 2017).

Sesame seeds are highly beneficial as seed contain 42-50% oil (25% protein, 16-18% carbohydrate and 42% essential linoleic acid) (Miah *et al*., 2015).

Sesame seeds are also rich in essential minerals, including magnesium, phosphorus, calcium, iron, and zinc. In addition, they contain vitamins B and E and have potent antioxidant properties (Langyan *et al*., 2022.

A wide range of animals can benefit from eating sesame oilcake, such as poultry, fish, cattle, goats, and sheep (Khan *et al*., 2009).

India and China are the world's largest producers of sesame, followed by Myanmar, Sudan, Uganda, Ethiopia, Nigeria, Tanzania, Pakistan and Paraguay (FAOSTAT, 2022). India ranks first in world with 19.47 Lakh ha area and 8.66 Lakh tones production.

India is one of the four major players in the global oilseeds/vegetable oils scenario, being one of the important oilseed grower, producer, importer, and exporter (De and Sinha, 2011).

India's major gains in oilseeds export have come from sesame apart from groundnut and gained 90% of European and 50% of US market in oilseed export (Vittal *et al*., 2004).

Vermicomposting is one of the biological processes in which the organic wastes has been converted into nutrient rich manure by the action of earthworms. The characteristic feature of vermicompost such as high porosity and moisture holding capacity increases the growth of pathogen free plants (Yadav and Garg 2019).

Vermicompost has positive effects on plant growth and soil structure. One of the attractive elements of vermicompost production is its positive effect on the environment. This is because the materials used as worm feed have a wide range of organisms that can rot in nature. Any material such as plant, animal, industrial and urban wastes can be transformed into beneficial fertilizers through the digestive system of worms (Edwards, 1995).

Intercropping is a sustainable strategy that includes cultivating many crop species together in the same area to take advantage of the beneficial interactions between them (Maitra *et al.*, 2021).

Organic materials are a major source of organic matter and plant nutrients, incorporating organic materials into soil results in improved soil physical attributes namely, soil structure, soil aggregate stability, water holding capacity, soil drainage, soil aeration and root penetration and soil chemical attributes namely. soil nutrient content and composition and soil pH (Carswell *et al*., 2001 and Murphy 2015).

Application of organic manures on sesame in form of crop residues and animal manure would most likely improve its yields and seed quality (Morris *et al*., 2002).

II. MATERIALS AND METHODS

The experiment was conducted during the kharif season of 2024-2025 at the Agriculture Research Farm of Himalayan University, Itanagar, Arunachal Pradesh. The soil of experimental plot was Sandy-loam and loamy sand in texture with pH ranges from 4 to 6. The experiment was conducted by following Randomized Block Design (RBD) with the construction of 21 plots. The Agriculture Research Farm is situated at 27.140 N latitude and 93.62° E longitudes and at an altitude of 320 m above mean sea level with total area of 83,743 sq. km. The site comes under the Eastern Himalayan region and the Agro - climatic zone is under sub- tropical zone of Arunachal Pradesh.

Sesame variety INDO US-5 and green gram variety KANIKA were used. Data were recorded on growth parameters (plant height, number of branches and leaves, biomass), yield attributes (capsule number, test weight).

III. RESULTS AND DISCUSSION

The present study highlights the significant influence of vermicompost and intercropping on the growth and yield of sesame. Among the seven treatments, T7 (100% RDF + Vermicompost 6 t/ha + Intercropping 2:2) consistently outperformed in almost all observed.

3.1 Plant Height:

At 90 DAS the maximum increase in plant height was found to be statistically significant in treatment T_7 (T7 100% RDF + Vermicompost 6 t/ha + intercropping (2:2) i.e., (84.3 cm) and T_6 (T6 100% RDF + Vermicompost 5 t/ha + intercropping (2:1) i.e., 83.0 (cm) and was found to be statistically at par with T_5 (T5 100% RDF + Vermicompost 5 t/ha + intercropping (2:2) i.e., (78.6 cm). Lowest plant height was observed in treatment T_1 (Control) i.e., 960.3 cm). This is because combination of vermicompost and intercropping likely to improved soil physical properties, enhanced moisture retention, and increased the availability of macro and micronutrients. It also contributed to better soil aeration and reduced weed competition, indirectly promoting the vertical growth of sesame plants. These findings are in agreement with studies by Sharma *et al*., (2017) and Patel *et al*., (2019).

3.2 Number of Leaves:

At 90 DAS the maximum increase in number of leaves was found to be statistically significant in treatment T_7 (T7 100% RDF + Vermicompost 6 t/ha + intercropping (2:2) i.e., 67.6 and T_6 (T6 100% RDF + Vermicompost 5 t/ha + intercropping (2:1) i.e., 66.3 and was found to be statistically at par with T_5 (T5 100% RDF + Vermicompost 4 t/ha + intercropping (2:2) i.e., 65.0. Lowest number of leaves was observed in treatment T_1 (Control) i.e., 60. These is because that combining vermicompost with inorganic fertilizer 50% VC + 50% NPK can improve sesame plant growth and seed nutrient content and is recommended for sesame production. These findings are similar to Shathi *et al.*, (2023) and Pandiyan *et al*., (2021).

3.3 Number of Branches:

At 90 DAS the maximum increase in number of branches was found to be statistically significant in treatment T_7 (T7 100% RDF + Vermicompost 6 t/ha + intercropping (2:2) i.e., 5.0 and T_6 (T6 100% RDF + Vermicompost 5 t/ha + intercropping (2:1) i.e., 4.8 and was found to be statistically at par with T_5 (T5 100% RDF + Vermicompost 5 t/ha + intercropping (2:2) i.e., 4.7. Lowest number of branches was observed in treatment T_1 (Control) i.e., 4.1. This can be attributed to the synergistic interaction between sesame and green gram, wherein the leguminous nature of green gram plays a crucial role in biological nitrogen fixation. The increased nitrogen availability in the rhizosphere likely stimulated greater vegetative growth in sesame, resulting in enhanced branching. These results are in similar with the findings of Kumar *et al.*, (2017) and Arpita *et al*., (2018).

3.4 Number of Capsule Plant^{-1}:

The maximum increase in number of capsule plant^{-1} was found to be statistically significant in treatment T_7 (T7 100% RDF + Vermicompost 6 t/ha + intercropping (2:2) i.e., 45.6 and T_6 (T6 100% RDF + Vermicompost 5 t/ha + intercropping (2:1) i.e., 44.9 and was found to be statistically at par with T_5 (T5 100% RDF + Vermicompost 5 t/ha + intercropping (2:2) i.e., 44.3. Lowest number of capsule/plants was observed in treatment T_1 (Control) i.e., 37.2. This is because the transition from flower to capsule depends on proper nutrient supply, pollination, and hormonal balance — all of which are positively influenced in an intercropping setup with a compatible legume like green gram. These results are like the findings of Kumar *et al.*, (2017) and Meena *et al*., (2020).

TABLE 1
IMPACT OF VERMICOMPOST AND INTERCROPPING ON THE MORPHOPHYSIOLOGICAL AND YIELD & YIELD ATTRIBUTES OF SESAME (*SESAMUM INDICUM* L.)

Treatments	Plant Height (cm)	No. of Branches	Leaves	Test weight (g)	Capsule length(cm)	Seed/ capsule	Capsule/ plant	Biological yield (t/ha)	Economical yield (t/ha)	Harvest index (%)
T1	60.3	4.1	60.0	2.1	2.5	31.4	37.2	0.74	0.22	30.03
T2	63.0	4.2	61.6	2.3	2.6	33.3	38.7	0.98	0.34	35.06
T3	69.3	4.4	62.3	2.6	2.6	34.0	40.5	0.95	0.35	37.46
T4	72.7	4.6	63.6	2.9	2.6	35.3	41.8	0.90	0.31	34.33
T5	78.6	4.7	65.0	3.2	2.8	35.8	44.3	0.99	0.35	35.80
T6	83.0	4.8	66.3	3.1	3.0	37.1	44.9	1.03	0.38	36.96
T7	84.3	5.0	67.0	3.7	3.6	38.6	45.6	1.22	0.46	37.50
SEd	2.6	0.07	1.3	0.16	0.2	0.4	0.7	0.03	0.01	0.79
S. Em (±)	1.8	0.05	0.9	0.12	0.1	0.3	0.5	0.02	0.00	0.56
CD	5.7	0.1	2.9	0.3	0.5	1.0	1.5	0.08	0.02	1.73
F test	S	S	S	S	S	S	S	S	S	S

3.5 Capsule Length (cm):

The maximum increase in capsule lengths was found to be statistically significant in treatment T_7 (T7 100% RDF + Vermicompost 6 t/ha + intercropping (2:2) i.e., 3.6 cm and T_6 (T6 100% RDF + Vermicompost 5 t/ha + intercropping (2:1) i.e., 3.0 cm and was found to be statistically at par with T_5 (T5 100% RDF + Vermicompost 5 t/ha + intercropping (2:2) i.e., 2.8 cm. Lowest number of capsule lengths was observed in treatment T_1 (Control) i.e., 2.5.These is because the application of both RDF and vermicompost ensured a balanced supply of macro and micronutrients. Vermicompost, being rich in humus, growth-promoting substances, and beneficial microbes, improved soil health, nutrient uptake, and enzymatic activity, which directly enhanced plant growth and capsule development. This finding is in line with the reports of Kumar *et al*., (2020) and Patel *et al*., (2018).

3.6 Number of Seed Capsule Plant^{-1}:

The maximum increase in number of seed capsule Plant^{-1} was found to be statistically significant in treatment T_7 (T7 100% RDF + Vermicompost 6 t/ha + intercropping (2:2) i.e., 38.6 and T_6 (T6 100% RDF + Vermicompost 5 t/ha + intercropping (2:1) i.e., 37.1 and was found to be statistically at par with T_5 (T5 100% RDF + Vermicompost 5 t/ha + intercropping (2:2) i.e., 44.3. Lowest number of seed/capsules was observed in treatment T_1 (Control) i.e., 35.8. These is because application of bulky organic manure likely played a vital role in improving the soil's physical, chemical, and biological properties. The improved soil structure and enhanced microbial activity fostered better nutrient availability and uptake, especially of essential macro-nutrients like nitrogen and phosphorus. These nutrients are crucial for the reproductive growth of sesame, and their improved availability under T7 conditions may have contributed to better pollination and fertilization, resulting in more seeds per capsule. These results are like the findings of Kumar *et al.*, (2017) and Arpita *et al*., (2019).

3.7 Test Weight (g):

The significant and the highest test weight was recorded in T_7 (T7 100% RDF + Vermicompost 6 t/ha + intercropping (2:2) i.e., 3.7g and T_6 (T6 100% RDF + Vermicompost 5 t/ha + intercropping (2:1) i.e., 3.1g and was found to be statistically at par with T_5 (T5 100% RDF + Vermicompost 5 t/ha + intercropping (2:2) i.e., 3.2g. Lowest test weight was observed in treatment T_1 (Control) i.e., 2.1g. The probable reason for recording highest test weight under treatment T_7 (T7 100% RDF + Vermicompost 6 t/ha + intercropping (2:2) is due to the increase in seed weight can be explained by the combined benefits of integrated nutrient management and intercropping, which positively influenced the physiological and nutritional status of sesame plants during seed development. This result aligns with the findings of Sharma *et al.,* (2019) and Meena *et al*., (2021).

3.8 Biological Yield (t/ha):

The highest biological yield was recorded under treatment T_7 (T7 100% RDF + Vermicompost 6 t/ha + intercropping (2:2) i.e., 2.0 t/ha and the lowest was seen under treatment T_1 (control). The synergistic effect of integrated nutrient management and intercropping creates favourable conditions for higher photosynthesis and efficient translocation of photosynthates. This increases both the economic yield (seed) and straw/stover yield, contributing to higher biological yield. Similar findings have been reported by Patel *et al*., (2017) and Arpita *et al.,* (2020),

3.9 Economical Yield (t/ha):

The significant and the highest biological yield was recorded in T_7 (T7 100% RDF + Vermicompost 6 t/ha + intercropping (2:2) i.e., 2.0 t/ha and T_6 (T6 100% RDF + Vermicompost 5 t/ha + intercropping (2:1) i.e., 1.8 t/ha and was found to be statistically at par with T_5 (T5 100% RDF + Vermicompost 5 t/ha + intercropping (2:2) i.e., 1.7 t/ha. Lowest biological yield was observed in treatment T_1 (Control) i.e., 1.1 t ha⁻1. The maximum economical yield was recorded under treatment T_7 (T7 100% RDF + Vermicompost 6 t/ha + intercropping (2:2) i.e., 69.9 t/ha. The synergistic effect of integrated nutrient management and intercropping creates favourable conditions for higher photosynthesis and efficient translocation of photosynthates. This increases both the economic yield (seed) and straw/stover yield. Similar findings have been reported by Patel *et al*., (2017) and Arpita *et al.,* (2020),

3.10 Harvest Index (%):

The significant and the highest harvest index was recorded in T_7 (T7 100% RDF + Vermicompost 6 t/ha + intercropping (2:2) i.e., 43.0% and T_6 (T6 100% RDF + Vermicompost 5 t/ha + intercropping (2:1) i.e., 41.3% and was found to be statistically at par with T_5 (T5 100% RDF + Vermicompost 5 t/ha + intercropping (2:2) i.e., 40.4%. Lowest harvest index was observed in treatment T_1 (Control) i.e., 30.3%. The probable reason for recording higher harvest index under treatment T_7 (T7 100% RDF + Vermicompost 6 t/ha + intercropping (2:2) is due to Vermicompost not only supplies nutrients but also improves soil structure, microbial activity, and moisture retention, creating a favourable environment for root and shoot growth. This synergistic effect enhances both biomass production and its efficient partitioning toward grain yield, ultimately increasing Harvest Index. These findings are consistent with the reports of Meena *et al.,* (2020) and Sharma *et al.,* (2018).

IV. CONCLUSION

The integrated application of 100% RDF with 6 t/ha Vermicompost and intercropping (2:2) significantly improved growth, yield, and quality parameters in sesame. T7 proved to be the most effective treatment, suggesting that combining organic inputs with legume intercropping can boost both agronomic performance and economic viability in sesame cultivation.

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Enhancing Rainfed Sesame (*Sesamum Indicum* L) Productivity and Economics through Organic Inputs and Legume Intercropping

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Abstract— *This study explores the impact of combining farmyard manure (FYM) with legume intercropping on sesame (Sesamum indicum L.) yield, and economics under rainfed conditions in Arunachal Pradesh. The experiment included 7 treatments that is T1 (control), T2 (FYM6t +Intercropping 2:1), T3 (FYM6t+intercropping 2:2), T4 (FYM7t+Intercropping 2:1), T5 (FYM7t +Intercropping 2:2), T6 (FYM8t + Intercropping 2:1) and T7 (FYM 8t +, Intercropping 2:2). The layout used was Randomized Block Design (RBD) with 3 replications. Results showed that FYM at 8 t/ha with a 2:1 sesame-to-black gram intercropping pattern (T6) recorded highest yield attributes of number of capsule per plant (33.00), number of seed per capsule (25.33), capsule length (3.07 cm), test weight (2.90 g), seed yield (0.39t/ha), straw yield (1.29t/ha) and harvest index (22.57%) as compared to all other treatments. It was also observed that the treatment T6 (FYM8t + Intercropping 2:1) recorded highest cost of cultivation (₹33,000), gross return (₹117,000), net returns (₹84,000/ha), and B.C ratio (3.55) as compared to all other treatments.*

This study confirms that integrating FYM and legume intercropping improves sesame performance while supporting ecological sustainability.

Keywords— Sesame, Farmyard Manure, Intercropping, Rainfed Agriculture, Yield, cost of cultivation, gross return, net return and B.C ratio.

I. INTRODUCTION

Sesame (Sesamum indicum L.) is one of the most ancient and significant oilseed crops cultivated in India, known for its high oil content (42–50%) and protein-rich seeds (20–25%) (Miah *et al*., 2015). It is particularly well-suited to rainfed conditions due to its short growth duration, adaptability to marginal soils, and drought tolerance. However, sesame productivity remains far below its genetic potential, especially in northeastern India, where it averages only 367 kg/ha (Anonymous, 2019), primarily due to low soil fertility, mono-cropping, and poor crop management practices (Pathak *et al*., 2017).

In the context of sustainable intensification of rainfed farming, the integration of organic nutrient sources and legume-based cropping systems offers an ecologically sound approach. Farmyard manure (FYM) is a valuable organic input that improves soil structure, microbial activity, and nutrient availability while reducing dependence on chemical fertilizers (Ramesh *et al*., 2010). It also enhances moisture retention and long-term soil productivity, making it suitable for dryland and hill agriculture (Zerihun *et al*., 2019).

Legume intercropping, particularly with crops like black gram (Vigna mungo), offers multiple benefits, including biological nitrogen fixation, improved land-use efficiency, weed suppression, and increased system stability (Mandal and Prama nick, 2014; Horwith, 1985). Intercropping has also been shown to improve the economic viability of smallholder farms by providing additional income and reducing input costs (Moola *et al*., 2020).

Although FYM and legume intercropping have been studied individually, there is limited research on their combined influence on sesame performance, especially in the rainfed hill ecosystems of Arunachal Pradesh. Understanding the interaction between different FYM levels and sesame-legume intercropping patterns is essential to developing sustainable and location-specific crop management strategies.

Therefore, the present study was undertaken to investigate the combined effect of organic inputs (FYM) and black gram intercropping on the growth, yield, quality, and economics of sesame under rainfed conditions. The results aim to provide integrated, low-input solutions for improving sesame productivity and farmer profitability in marginal environments.

II. MATERIALS AND METHODS

The experimental trial was carried out during kharif 2024 at Agriculture research farm of Himalayan University. The agriculture Research Farm is situated at 27.14ºN latitude and 93.62º E longitudes. The location of jollang was tropical climate zone with an average rainfall of 3500-4000mm at an average meters from mean sea level. The soil of experimental plot was sandy loam and loamy sandy in texture with pH ranges from 4 to 6. The site comes under the Eastern Himalayan region and the Agro - climatic zone is under sub- tropical zone of Arunachal Pradesh. Sesame variety INDO US-5 and Black gram variety Jaigrow 75 were used. Data were recorded on Yield Attributes like capsules/plant, seeds/capsule, Test weight (1000 seed weight), seed yield (t/ha) straw yield (t/ha), harvest index (%) and Economic analysis included cost of cultivation, gross return, net return and B.C ratio were recorded and statistically analyzed using analysis of variance (ANOVA) as applicable to Randomized Block Design.

III. RESULTS AND DISCUSSION

3.1 The statistical data regarding yield and yield Attributes is presented in Table no:1:

3.1.1 No. of capsule plant^{-1}:

Maximum number of capsule plant^{-1} was recorded in treatment T6 (FYM8t+Intercropping2:1) i.e., 33.00 which is at par with treatment T7 (FYM8t+Intercropping2:2) i.e., 32.67. Lowest number of capsule plant^{1} recorded at T1 (control) i.e., 21.

The probable reason for recording higher number of capsule plant^{-1} in T6 (FYM+ Intercropping 2:1) the possible reason could be due to higher nutrient uptake and improved physiological functions. Similar improvements in yield attributes due to FYM and legume intercropping were reported by Sharma *et al*. (2020), Arpita *et al*. (2021) and Aglawe *et al*. (2021).

TABLE 1
EFFECT OF FARMYARD MANURE AND INTERCROPPING ON YIELD AND YIELD ATTRIBUTES OF SESAME

Treatments	No. of capsule plant^{-1}	No. of seed capsule^{-1}	Capsule length(cm)	Test weight (g)	Seed yield (t/ha)	Straw yield (t/ha)	Harvest index (%)
T	21.00	18.00	2.60	2.17	0.16	0.88	15.04
T_2	29.00	19.67	2.97	2.43	0.22	1.12	16.12
T_3	28.67	20.33	2.63	2.60	0.22	1.27	15.62
T_4	31.67	21.67	2.93	2.80	0.22	1.24	15.07
T_5	32.33	23.67	2.90	2.77	0.24	1.25	16.06
T_6	33.00	25.33	3.07	2.90	0.39	1.29	22.57
T_7	32.67	24.00	3.00	2.87	0.31	1.27	19.48
SED	2.48	1.62	0.38	0.38	0.06	0.14	3.22
SEM (±)	1.75	1.14	0.27	0.24	0.04	0.10	2.28
CD	5.40	3.52	0.82	0.73	0.14	0.30	7.02

3.1.2 No. of seed capsule^{-1}:

Maximum number of seed capsule^{-1} was recorded in treatment T6 (FYM8t+Intercropping2:1) i.e., 25.33 which is at par with treatment T7 (FYM8t+Intercropping2:2) i.e., 24. Lowest number of seed capsule^{-1} recorded at T1 (control) i.e., 18.

The probable reason for recording higher number of seed capsule^{-1} in T6 (FYM8t+Intercropping2:1) the possible reason could be due to application of FYM and legume intercropping, improved physiological functions or due to better pollination and ovary development supported by balanced nutrition from FYM and black gram intercropping. Similar improvements in yield attributes due to FYM and legume intercropping were reported by Arpita *et al*. (2021), Saad *et al*. (2022) and Ahmed *et al*. (2023).

3.1.3 Capsule Length (cm):

Maximum number of capsule length was recorded in treatment T6 (FYM8t+Intercropping2:1) i.e., 3.07cm which is at par with treatment T7 (FYM8t+Intercropping2:2) i.e., 3cm. Lowest number of capsule length recorded at T1 (control) i.e., 2.6cm.

The probable reason for recording higher number of capsule length in T6 (FYM8t+Intercropping 2:1) could be due to higher nutrient uptake especially phosphorous and potassium and improved physiological functions. Similar improvements in yield attributes due to FYM and legume intercropping were reported by Nadeem *et al*. (2015), Parmar *et al*. (2020) and Arpita *et al*. (2021).

3.1.4 Test weight (g):

Maximum number of test weight was recorded in treatment T6 (FYM8t+Intercropping2:1) i.e., 2.9g which is at par with treatment T7 (FYM8t+Intercropping2:2) i.e., 2.87g. Lower number of test weight recorded at T1 (control) i.e., 2.17g.

The probable reason for recording higher number of test weight in T6 (FYM8t+Intercropping 2:1) the possible reason could be due to application of FYM and intercropping with legume. Similar improvements in yield attributes due to FYM and legume intercropping were reported by Ali et al. (2012), Moola *et al*. (2020), and Arpita *et al* (2021)

3.1.5 Seed yield (tonne ha^{-1}):

The significant and highest seed yield (0.39t ha^{-1}) was recorded in treatment T6 (FYM8t+Intercropping2:1) which is at par with treatment T7 (FYM8t+Intercropping2:2) i.e., (0.31t ha$^{-1)}$. Lowest number of grain yield recorded at T1 (control) i.e., (0.16t ha^{-1}).

The probable reason for recording higher seed yield (0.39t ha^{-1}) in T6 (FYM8t+Intercropping2:1) due to improved nutrient cycling and nitrogen fixation from legumes. This is supported by studies like those of puste *et al*. (2014), Moola *et al.* (2020) and Sharma *et al*. (2020).

3.1.6 Straw yield (tonne ha^{-1}):

The significant and highest straw yield (1.29t ha^{-1}) was recorded in treatment T6 (FYM8t+Intercropping2:1) which is at par with treatment T7 (FYM8t+Intercropping2:2) i.e., (1.27t ha$^{-1)}$. Lowest number of straw yield recorded at T1 (control) i.e., (0.88t ha^{-1}).

The probable reason for recording higher straw yield (1.29t ha^{-1}) in T6 (FYM8t+Intercropping2:1) may be due to balance nutrient supplied and nitrogen fixation from legumes. Similar findings was reported by puste *et al*. (2014), Moola *et al.* (2020) and Parmar *et al*. (2020).

3.1.7 Harvest index (%):

The significant and highest harvest index (22.57%) was recorded in treatment T6 (FYM8t+Intercropping2:1) which is at par with treatment T7 (FYM8t+Intercropping2:2) i.e., (19.48%). Lowest number of harvest index recorded at T1 (control) i.e., (15.04%).

The probable reason for recording higher harvest index (22.57%) in T6 (FYM8t+Intercropping2:1) may be due to integrated nutrient and intercropping. This is supported by studies like those of puste *et al*. (2014), Moola *et al*. (2020), Reddy and Goud (2022). Who reported improved HI under integrated nutrient and intercropping systems?

3.2 The statistical data regarding Economics is presented in Table no:2:

3.2.1 Cost of cultivation (INR ha^{-1}):

In Cost of cultivation (33,000 INR ha^{-1}) was found to be highest in treatment T6 (FYM8t+Intercropping2:1), and the minimum cost of cultivation (20,000 INR ha^{-1}) was found to be in treatment T1 (control).

3.2.2 Gross return (INR ha^{-1}):

Gross return (117,000 INRha^{-1}) was found to be highest in treatment T6 (FYM8t+Intercropping2:1), and the minimum gross returns (48,000 INR ha^{-1}) was found to be in treatment T1 (control) as compare to other treatments.

TABLE 2
ECONOMIC EFFECTS OF FARMYARD MANURE AND INTERCROPPING ON SESAME

Treatments	Cost of cultivation (INR/ha)	Gross return (INR/ha)	Net return (INR/ha)	B.C ratio
T1	20,000	48,000	28,000	2.40
T2	27,000	66,000	39,000	2.44
T3	27,000	66,000	39,000	2.44
T4	29,000	72,000	43,000	2.48
T5	29,000	72,000	43,000	2.48
T6	33,000	117,000	84,000	3.55
T7	32,500	114,000	81,500	3.51

3.2.3 Net returns (INR ha^{-1}):

Net returns (84,000 INR ha^{-1}) was found to be highest in treatment T6 (FYM8t+Intercropping 2:1), and the minimum net returns (28,000 INR ha^{-1}) was found to be in treatment T1 (control) as compare to other treatments.

3.2.4 Benefit cost ratio (B:C):

Benefit cost ratio (3.55) was found to be highest in treatment T6 (FYM8t+Intercropping 2:1), and the minimum benefit ratio (2.40) was found to be in treatment T1 (control) as compare to other treatments.

Significant difference with regard to net returns and B:C ratio were observed in treatment T6 (FYM8t+Intercropping (2:1) *i.e.*,3.55 was significantly superior to other treatments with highest net return value of 84,000 INR. However, minimum net return value of 28,000 INR and B:C ration 2.40 was observed in treatment T1 (control).

The probable reason for recording significant and higher net return and B:C ratio under treatment T6 (FYM8t+Intercropping 2:1) this might be due to efficient utilization of resources through FYM application and legume-based intercropping. FYM improves soil structure, microbial activity, and nutrient availability, while legumes like black gram helps in biological nitrogen fixation, further boosting sesame productivity. These results are supported by the findings of Sarma *et al*. (2016), Arpita *et al*. (2021), who reported that sesame intercropped with green gram and supplemented with organic inputs produced significantly higher net returns and profitability compared to sole cropping. Similarly, Parmar *et al*. (2020) observed a B:C ratio above 1.5 in sesame under integrated nutrient management with FYM and biofertilizers.

In contrast, the control treatment (T1) recorded the lowest net return (28,000 INR/ha) and lowest B:C ratio (2.40), mainly due to reduced crop performance under nutrient-deficient conditions and absence of intercrop benefit.

IV. CONCLUSION

The combined application of FYM (8 t/ha) and legume intercropping (2:1) significantly improves sesame productivity and profitability under rainfed conditions. This approach offers a sustainable and eco-friendly alternative to intensive chemical inputs.

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Effect of Bone Meal and Intercropping on Productivity and Quality of Sesame (*Sesamum indicum* L.)

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Abstract— *A field experiment was conducted in Kharif season of 2024–2025 at the Agricultural Research Farm, Department of Agronomy, Himalayan University, Jollang, Itanagar, Arunachal Pradesh. The soil of experimental plot was sandy loam and loamy sandy in texture with pH ranges from 4 to 6. The experiment was laid out in a Randomized Block Design (RBD) with seven treatments each replicated thrice three. The treatments which are T1: Control, T_2:Bone meal at 70 kg/ha.+ intercropping (2:1), T_3: Bone meal at 70 kg/ha. +intercropping (2:2), T_4: Bone meal at 70 kg/ha.+ Intercropping (2:1), T_5: Bone meal at 70 kg/ha. + intercropping (2:2), T_6: Bone meal at 70 kg/ha.+ intercropping (2:1), T_7: Bone meal at 70 kg/ha.+ Intercropping (2:2). The results showed maximum productivity of were recorded significantly higher in the treatment T_7 which is Bone meal at 70 kg/ha.+Intercropping (2:2), number of capsule/plant (.33.67), capsule length (3.5cm) , seeds/capsule (78), test weight (3.2g), economic yield (0.3 t/ha), biological yield (2 t/ha), but in harvest index T1: Control has shown maximum result i.e., (19.19) and maximum quality of oil content in sesame (6.35%) and in protein content (35.06%) were recorded in the treatment T_7 as compared to all the other treatments.*

Keywords— Bone meal, Intercropping, Sesame, Yield and quality.

I. INTRODUCTION

Sesame (*Sesamum indicum* L.) is one of the oldest and most important oilseed crops, cultivated extensively in tropical and subtropical regions across more than 70 countries. It is highly valued for its adaptability to adverse climatic conditions, particularly drought and high temperatures, due to its deep root system and low water requirement. India ranks among the leading producers of sesame, with cultivation spread over 1.77 million hectares and a productivity of 456 kg/ha (Anonymous, 2016; Singh *et al., (*2017). Sesame seeds are rich in oil (46–52%), proteins, antioxidants, and essential minerals such as calcium, magnesium, and iron. These properties make sesame a functional food with applications in the culinary, cosmetic, and pharmaceutical industries. However, despite its resilience and economic value, sesame yields remain low, primarily due to poor soil fertility, limited input use, and traditional agronomic practices.

Among organic nutrient sources, bone meal has shown considerable potential in improving soil fertility and crop productivity. It is a slow-release organic fertilizer rich in phosphorus and calcium, essential for root development, photosynthesis, and cell wall strengthening. Application of bone meal improves phosphorus availability in the rhizosphere, particularly in acidic or phosphorus-deficient soils, thereby enhancing early plant vigor and yield components. Its use not only supports sustainable nutrient management but also aligns with organic farming practices aimed at reducing chemical fertilizer dependence (Tesfaye *et al., (*2021) Sharma *et al.,* (2013), Hussain *et al., (*2020).

In addition to organic nutrient supplementation, intercropping is a promising agroecological practice that improves land use efficiency, resource utilization, and overall system productivity. When sesame is intercropped with compatible species, particularly legumes, it benefits from enhanced soil nitrogen through biological fixation, reduced weed competition, and minimized pest and disease pressure. Intercropping also contributes to soil conservation and income diversification, making it especially beneficial for smallholder farmers aiming to improve productivity without expanding cultivated land (Agegnehu *et al., (*2017), Lithourgidis *et al., (*2011).

II. MATERIALS AND METHODS

The experimental trial was conducted during the Kharif season of 2024 at the Agricultural Research Farm of Himalayan University, located at 27.14° N latitude and 93.62° E longitude. The site, situated in Jollang, falls under a tropical climatic zone, receiving an average annual rainfall of 3500–4000 mm and lying at a moderate elevation above mean sea level. The soil of the experimental field was predominantly sandy loam to loamy sand in texture, with a pH ranging from 4.0 to 6.0.

The experiment followed the recommended dose of fertilizers (NPK: 20:20:30), and bone meal was applied according to the treatment specifications. Sowing was followed by gap filling to ensure uniform plant population, and although irrigation was provided, it was not applied regularly due to frequent natural rainfall.

Observations on productivity after the harvest the yields parameters such as number of capsules per plant, seeds per capsule, test weight (1000-seed weight), seed yield (t/ha), biological yield (t/ha), and harvest index (%) and quality of oil and protein content (%) in sesame were recorded. Data collected were statistically analyzed using Analysis of Variance (ANOVA) appropriate for a Randomized Block Design (RBD).

III. RESULTS AND DISCUSSION

3.1 The statistical data regarding quality parameters is presented in Table no:1:

3.1.1 Oil content in sesame (%):

The significant and highest oil content (6.35 %) was recorded in treatment T_7 Bone meal at 80kg/ha + intercropping at 2:2 and closely followed by T_6 Bone meal at 80kg/ha + intercropping at 2:1 i.e., 5.98 %. The lowest oil content was recorded in T1 i.e., 3.62 %.The increase under T7 may be due to improved phosphorus availability enhancing lipid biosynthesis, along with better nutrient synergy from intercropping systems (Ali *et al.*, 2015; Patel *et al.*, 2020). Similar findings by Rani and Babu (2018) also suggest that integrated nutrient and cropping systems positively influence sesame oil content.

3.1.2 Protein content in sesame (%):

The significant and highest protein content (35.06 %) was recorded in treatment T_7 Bone meal at 80kg/ha + intercropping at 2:2 and closely followed by T_6 Bone meal at 70kg/ha + intercropping at 2:2 i.e., 32.98%. The lowest protein content was recorded in T_5 Bone meal at 75kg/ha + intercropping at 2:2 i.e., 27.14 %. Which enhanced protein levels under T_7 may be attributed to better phosphorus availability, which is essential for nitrogen metabolism and protein synthesis (Ali & Mahmoud, (2014). The use of bone meal also improves soil microbial activity, indirectly boosting protein accumulation (Nweke *et al., (*2018), Ghosh *et al., (*2020).

3.2 The statistical data representing yield and yield attributes presented in Table no. 2:

3.2.1 No. of capsule plant^{-1}:

The number of capsules per plant at 60 and 90 DAS showed significant variation among treatments. The highest number was recorded in T7 (Bone meal at 80 kg/ha + intercropping 2:2) with 21.00 and 33.67 capsules, respectively, while the lowest was in control (T1) with 5.66 and 8.33 capsules. The improvement in T7 may be attributed to enhanced phosphorus availability from bone meal and better nutrient utilization through intercropping, which supports reproductive growth (Adeyemo *et al., (*2019), Singh *et al., (*2021), Ogunyemi *et al., (*2018).

3.2.2 No. of seed capsule^{-1}:

The number of seeds per capsule at 90 DAS (Table 4.10) was significantly influenced by treatments, with the highest count in T7 (Bone meal at 80 kg/ha + intercropping 2:2) at 78 seeds per capsule, while the lowest was in T1 (Control) with 55 seeds. The increased seed number in T7 may be due to improved nutrient availability, especially phosphorus from bone meal, which enhances reproductive development, and intercropping, which promotes efficient nutrient use and better pollination (Ghosh *et al., (*2020), Adeyemo *et al., (*2019), Rani & Babu, (2018).

3.2.3 Capsule Length (cm):

Capsule length at 60 and 90 DAS was significantly highest in T7 (Bone meal at 80 kg/ha + intercropping 2:2), recording 2.2 cm and 3.5 cm respectively, while the lowest was in control (T1) with 1.2 cm and 2.3 cm. The improvement in T7 may be due to better phosphorus availability from bone meal and enhanced nutrient uptake through intercropping (Adeyemo *et al., (*2019) Sharma *et al., (*2020) Ogunyemi *et al., (*2018).

3.2.4 Test weight (g):

Test weight of 1000 seeds at harvest was significantly influenced by treatments, with the highest value in T7 (Bone meal at 80 kg/ha + intercropping 2:2) at 3.2 g and the lowest in T1 (Control) at 2.50 g. The increase in test weight under T7 may be due to improved nutrient availability and assimilation during seed filling, enhanced by phosphorus from bone meal and better crop synergy through intercropping (Sharma *et al., (*2020), Singh *et al., (*2021), Adeyemo *et al., (*2019).

3.2.5 Economic yield (t/ha^{-1}):

Economic yield (t ha^{-1}) at harvest was significantly influenced by treatments, with T7 (Bone meal at 80 kg/ha + intercropping 2:2) recording the highest yield of 0.30 t ha^{-1}, while the lowest was in T1 (Control) at 0.17 t ha^{-1}. The increased yield in T7 could be due to improved nutrient availability from bone meal and enhanced growth and resource use efficiency under intercropping, which together promote better seed development and harvest output (Adeyemo *et al., (*2019), Sharma *et al., (*2020), Ogunyemi *et al., (*2018).

3.2.6 Biological yield (t/ha):

Biological yield (t ha^{-1}) at harvest was significantly affected by the treatments, with the highest yield in T7 (Bone meal at 80 kg/ha + intercropping 2:2) at 2.00 t ha^{-1}, and the lowest in T1 (Control) at 0.90 t ha^{-1}. The increase in T7 can be linked to better plant growth and biomass accumulation due to the combined effect of slow-release phosphorus from bone meal and improved resource utilization in the intercropping system (Singh *et al., (*2021), Adeyemo *et al. (*, 2019), Ogunyemi *et al., (*2018).

3.2.7 Harvest index (%):

Harvest index (%) at harvest was significantly influenced by treatments, with the highest value in T6 (Bone meal at 80 kg/ha + intercropping 2:1) at 21.5%, and the lowest in T7 (Bone meal at 80 kg/ha + intercropping 2:2) at 15.14%. The higher harvest index in T6 suggests better partitioning of assimilates towards economic yield, while the lower value in T7 may be due to greater vegetative biomass reducing the proportion of economic yield (Sharma *et al., (*2020), Singh *et al., (*2021), Adeyemo *et al.,* 2019).

TABLE 1
EFFECT OF BONE MEAL AND INTER CROPPING ON QUALITY OF SESAME

Treatments No.	Oil (%)	Protein (%)
T1	3.62	27.72
T_2	4.17	32.98
T_3	4.31	28.02
T_4	4.96	30.5
T_5	5.38	27.14
T_6	5.98	32
T_7	6.35	35.07
SEd	0.31	0.64
SEm(±)	0.22	0.45
CD	0.61	1.25

TABLE 2
EFFECT OF BONE MEAL AND INTERCROPPING ON PRODUCTIVITY OF SESAME

Treatments	No. of capsule plant^{-1}	No. of seed capsule^{-1}	Capsule length(cm)	Test weight(g)	Seed/Economic yield(t/ha)	Biological yield(t/ha)	Harvest index(%)
T1	8.33	55	2.3	2.5	0.17	0.9	19.17
T_2	14.33	64	3	2.6	0.2	1.16	17.21
T_3	17.33	67	2.8	2.57	0.21	1.06	19.42
T_4	21.33	71	3.13	2.7	0.24	1.36	17.4
T_5	25.33	74	3.07	2.8	0.26	1.28	20.07
T_6	29.33	76	3.37	3	0.29	1.72	16.63
T_7	33.67	78	3.5	3.2	0.3	2	15.14
SEd	0.62	2	0.29	0.06	0.01	0.05	1.2
S.Em (±)	0.44	1.41	0.21	0.04	0.01	0.04	0.85
CD	1.21	3.92	0.57	0.12	0.02	0.1	2.36

IV. CONCLUSION

Based on the findings of the investigation it may be concluded that T_7 (Bone meal at 80 kg/ha + intercropping 2:2) performed exceptionally in all growth and yield parameters and in obtaining maximum seed yield of sesame. Hence, (Bone meal at 80 kg/ha + intercropping 2:2) is beneficial for future use.

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Effect of Soil and Foliar Application of Micronutrients on Yield parameters of Groundnut (K-6) (*Arachis hypogaea* L.) in Red Sandy loamy Soils

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Abstract*—** *A field experiment entitled* ***—Effect of Soil and Foliar application of micronutrients on Yield parameters of Groundnut (Arachis hypogaea** L.)* ***(K-6) in Red Sandy Loamy Soils *was conducted during rabi'2024. The experiment was laid out in Randomized Block Design (RBD) and replicated thrice with ten treatments. The treatments consisted of T_1(Control), T_2(RDF + FYM@ 10 t ha^{-1}), T_3 (RDF+ soil application of $ZnSO_4$@ 16 kg ha^{-1} as a basal), T_4(RDF + soil application of $FeSO_4$@ 10 kg ha^{-1} as a basal), T_5(RDF + soil application of borax @ 10 kg ha^{-1}asabasal),T_6 (RDF + soil application of $ZnSO_4$@ 16kgha^{-1} + $FeSO_4$@ 10kgha^{-1}+ borax @ 10 kg ha^{-1} as a basal),T_7FoliarApplication of$ZnSO_4$@0.2 % at 30DAS and 60 DAS, T_8 Foliar application of$FeSO_4$@0.5% at30and 60 DAS, T_9 Foliar application of borax @0.25 % at 30and 60 DAS,T_{10}Foliar application of $ZnSO_4$ @ 0.2 % + $FeSO_4$ @ 0.5 % + borax @0.25% at 30 and 60 DAS. The results indicated that application of each and combined micronutrients through soil methods significantly influenced the Yield parameters and quality parameters of groundnut crop. The yield Parameters and yield viz. number of pods plant^{-1}(12.93), pod yield (2506 kg ha^{-1}) and haulm yield (3339 kg ha^{-1}) of groundnut were recorded with application of RDF + FYM @10 t ha^{-1} and found significant over control (T1). From the findings it can be concluded that Application of FYM and combined soil application of all micronutrients followed by individual micronutrient application alone found better than foliar application of each micronutrient alone. The highest Yield parameters were obtained with the combined soil application of all micronutrients.*

***Keywords*— FYM, Micro Nutrients, Foliar Application, Yield Parameters.**

I. INTRODUCTION

Groundnut (*Arachis hypogaea* L.) is one of the important legume and oil seed crops of tropical and semiarid tropical countries, where it is a major source of edible oil and vegetable protein. Groundnut kernels contain 47-53 % oil, 25-30 % protein, 20 % carbohydrates and 5 % fiber and ash, and make a substantial contribution to human nutrition. Its oil cake is used as an important nutrient rich cattle feed. Inclusion of groundnut in cropping sequence serves as an important rotation crop as it fixes atmospheric nitrogen and increases the fertility of soil.

Globally, groundnut cultivation is mainly confined to Asia. India ranks first in terms of groundnut output area and second in terms of production volume. The global production of groundnut is 47.02 million metric tons (USDA2018- 19). In India, groundnut is cultivated in an area of 4.91 million hectares producing 9.18 million tonnes with a productivity of 1868 kg ha^{-1} (Ministry of Agriculture and Farmers Welfare, GOI, 2018-19). It is India's top oil seed product and is also referred to as peanut, monkey nut, and manila nut. In the world, groundnuts are used for 12% seed purposes, 37% confectionery uses, and 50% oil extraction uses. Approximately 46.70 percent of groundnuts are used for oil production, according to Satish *et al.*

Major production constraints which could be attributed to lower productivity of groundnut in India are mainly due to low fertile marginal lands with low input supply, low plant population, incidence of pests and diseases, imbalanced use of nutrients and lack of application of micronutrients especially zinc, iron and boron. In India, multi-nutrient deficiencies are widely causing poor crop yields (Singh, 2009a).Groundnut responds well to secondary and micronutrient fertilization. The estimated yield loss in groundnut due to the deficiencies of Fe, Zn and B in India are 10-22, 30-40% and 16- 26%respectively.Therefore, it is most essential to pay a great attention to the nutrition of the groundnut to enhance its productivity. Soil analysis of Indian fields has indicated that they are medium to low in the iron, zinc and boron content, which are found to play an important role in plant nutrition. The micronutrients are applied by both soil and foliar methods. The most significant advantage of soil-applied nutrients is that this method supplies nutrients where the plants are designed to take in nutrients *i.e*., at the roots. The roots of higher plants are adapted to uptake nutrients and water from the soil and distribute them throughout the plant through the plant's conductive tissues. The foliar applied nutrients promote rapid uptake of nutrients as these nutrients are applied directly to the plant rather than the soil. Now the studies on independent use of these micronutrients and combined effect of these nutrients on yield and yield attributes is well documented, in groundnut production.

II. MATERIALS AND METHODS

The field experiment was conducted during *rabi 2024-25* at Vidavalur (Farmer's Farm), the Field situated at 14°35' N latitude and 80° 06' E longitude at an altitude of 5.05 meters above mean sea level (MSL). It is about 5 km away from Bay of Bengal in SPSR Nellore District of Andhra Pradesh, India. The experimental plot's soil was Red sandy loam in texture, virtually neutral in soil reaction (pH 6.75), low in organic carbon (0.55 %), available N (210.6 kg/ha), available Phosphorous (20.40 kg/ha), and available K (200.50 kg/ha) and low in zinc (0.5 ppm), iron (2.25 ppm) and boron (0.45ppm).

The experiment was designed in the Randomized Block Design (RBD) method, with ten treatments Replicated thrice. RDF of 20:40:50 NPK kg/ha and gypsum at 500kg/ha was applied to all treatments except control, and the Micro nutrients Zinc, Boron and Iron were applied as Soil application and foliar spray according to the treatments. The ten treatment combinations are given under Table 1.

TABLE 1
MICRONUTRIENT FERTILIZATION TREATMENTS APPLIED TO GROUNDNUT.

T1	Control
T2	FYM @ 10 t ha^{-1}
T3	Soil application of Zinc sulphate (ZnSO4) @ 16 kg ha^{-1} as a basal
T4	Soil application of Ferrous sulphate (FeSO4) @ 10 kg ha^{-1}as a basal
T5	Soil application of Borax @ 10 kg ha^{-1} as a basal
T6	Soil application of ZnSO4 @ 16 kg ha^{-1} + FeSO4 @ 10 kg ha^{-1} + Borax @ 10 kg ha^{-1} as a basal
T7	Foliar application of ZnSO4 @ 0.2% at 30 DAS and 60 DAS
T8	Foliar application of FeSO4 @ 0.5% at 30 and 60 DAS
T9	Foliar application of Borax @ 0.25% at 30 and 60 DAS
T10	Foliar application of ZnSO4 @ 0.2% +FeSO4 @ 0.5% + Borax @ 0.25% at 30 and 60 DAS

RDF (25 N: 40 P2O5: 50 K2O) kg ha^{-1} and Gypsum @ 500 kg ha^{-1} is applied to all treatments.

Kadiri-6 variety is used for this experiment. Manual seeding was done at a seed rate of 125 kg/ha at a depth of 3-4 cm and spacing of 30 cm X 10 cm. Plant growth parameters were documented at regular intervals from germination to harvest, and yield parameters were recorded after harvest. These factors were statistically analyzed using the Randomized Block Design analysis of variance (ANOVA). Statistical significance was tested by applying F-test at 0.05 level of probability and critical differences were calculated for those parameters which turned out to be significant ($P<0.05$) in order to compare the effects of different treatments.

III. RESULTS AND DISCUSSIONS

3.1 Yield and Yield Parameters:

The data on yield and yield attributes *viz.*, number of pods $plant^{-1}$, pod yield, kernel yield, haulm yield, harvest index and shelling percentage as influenced by micronutrient fertilization are presented in Table 2. Among the treatments tested, T2 (RDF + FYM @ 10 t ha^{-1}) recorded significantly more number of pods $plant^{-1}$ (12.93), pod yield (2506 kg ha^{-1}) and haulm yield (3339 kg ha^{-1}) over treatments T1, T8, T7 and T9. However, it remained on par with treatments received with soil application of sole and combined application of micronutrients (T6, T5, T3 and T4) and combined foliar application (T10). Whereas, the treatment T2 (RDF + FYM @ 10 t ha^{-1}) recorded significantly the highest shelling percentage (74.48%) and found on par with all the remaining treatments except T1 (control). The maximum kernel yield (1864 kg ha^{-1}) was recorded with T2 (RDF + FYM @ 10 t ha^{-1}) treatment, and proved its superiority over treatments (T1, T8, T7, T9 and T10). However, it was found on par with soil application of micronutrient treatments (T6, T5, T3 and T4). This increase in yield and yield attributes might be due to availability of sufficient nutrients by mineralization of basic organic and inorganic sources of nutrients to plant which was reflected on formation of higher sink capacity that led to increased number of pods plant^{-1}, pod yield, kernel yield, haulm yield and shelling percentage. Among soil and foliar application of micronutrients, application of micronutrients in combination increased the supply of micronutrients required for growth and development which resulted in increase of dry matter accumulation in the reproductive parts and formation of higher sink capacity with the application of micronutrients. These results are in conformity with findings of Elayaraja and Singaravel (2012), Abd-EL Kaderand Mona (2013), Kamalakannan (2017), Nakum *et al*. (2019) and Sabra *et al*. (2019). There was no significant influence on harvest index due to the application of micronutrients.

TABLE 2
EFFECT OF MICRONUTRIENT FERTILIZATION ON YIELD ATTRIBUTES AND YIELD OF GROUNDNUT

Treatments	No of pods plant^{-1}	Pod yield (kg ha^{-1})	Kernel yield (kg ha^{-1})	Haulm yield (kg ha^{-1})	Harvest Index	Shelling (%)
T1: Control (RDF)	7.47	1769	1087	2455	41.89	61.23
T2: RDF+FYM @ 10 t ha^{-1}	12.93	2506	1864	3339	42.93	74.48
T3: RDF+ soil application of ZnSO4@ 16 kg ha^{-1} as a basal	11.27	2228	1614	3002	42.73	73.24
T4: RDF+ soil application of FeSO4@ 10 kg ha^{-1} as a basal	10.80	2216	1596	2975	42.72	72.42
T5: RDF+ soil application of Borax @ 10 kg ha^{-1} as a basal	11.67	2271	1642	3053	42.78	72.86
T6: RDF+ soil application of ZnSO4@ 16 kg ha^{-1} + FeSO4@ 10 kg ha^{-1}+ Borax @ 10 kg ha^{-1} as a basal	12.47	2393	1763	3191	42.90	73.40
T7: RDF+ foliar application of ZnSO4@ 0.2% at 30 and 60 DAS	9.67	2057	1423	2853	42.00	70.02
T8: RDF+ foliar application of FeSO4@ 0.5% at 30 and 60 DAS	9.47	1977	1357	2765	41.81	68.95
T9: RDF+ foliar application of Borax @ 0.25% at 30 and 60 DAS	9.87	2092	1484	2877	42.17	70.93
T10:RDF+ foliar application of ZnSO4@ 0.2% + FeSO4@ 0.5% + Borax @ 0.25% at 30 and 60 DAS	10.60	2190	1548	2973	42.72	71.43
SE m±	0.78	113.15	104.51	141.8	1.49	2.14
CD (P=0.05)	2.34	336.18	310.52	421.47	NS	6.36

3.2 Economics:

The data (Table 3) on cost of cultivation (Rs ha^{-1}), gross returns (Rs ha^{-1}), Net returns (Rs ha^{-1}) and benefit: cost (B:C) ratio was significantly influenced by sole and combined application of micronutrients through soil and foliar method. The highest gross returns (Rs 135548 ha^{-1}) realized with T2 (RDF + FYM @ 10 t ha^{-1}) and found significant over T1, T8, T7, T9 and T10. However, it was found on par with soil application of micronutrient treatments (T6, T5, T3 and T4). Whereas, significantly higher net returns (Rs 77229 ha^{-1})were registered with T6 over control (T1) and foliar application of each micronutrient (T2, T8 and T7) and it was found on par with the treatments T5, T3, T4, T10 and T9. The highest benefit cost ratio (3.52) was recorded significantly with combined soil application of micronutrients (T6) over other treatments and found on par with the treatments T5, T4, T3 and T10.This might be because of higher productivity and favorable response of groundnut to the RDF + Zn+ Fe + B. Similar results were reported by Rahevar *et al*. (2015) . Combination of RDF with FYM was proved less profitable because of higher cost involved in supplying larger quantities of manure to meet the nutrient requirement of crop compared to fertilizers. These results are in agreement with the findings of Sultana (2001) and Gowthami and Ananda (2019).

TABLE 3
ECONOMICS OF DIFFERENT TREATMENTS OF GROUNDNUT AS INFLUENCED BY MICRONUTRIENT FERTILIZATION

Treatments	Cost of cultivation (₹ ha^{-1})	Gross returns (₹ ha^{-1})	Net returns (₹ ha^{-1})	B:C ratio
T1: Control (RDF)	26570	95770	69200	2.60
T2: RDF+FYM @ 10 t ha^{-1}	58320	135548	77229	1.32
T3: RDF+ soil application of ZnSO4@ 16 kg ha^{-1} as a basal	27832	120511	92680	3.33
T4: RDF+ soil application of FeSO4@ 10 kg ha^{-1} as a basal	27440	119887	92447	3.37
T5: RDF+ soil application of Borax @ 10 kg ha^{-1} as a basal	27970	122848	94879	3.39
T6: RDF+ soil application of ZnSO4@ 16 kg ha^{-1} + FeSO4@ 10 kg ha^{-1}+ Borax @ 10 kg ha^{-1} as a basal	28602	129422	100820	3.52
T7: RDF+ foliar application of ZnSO4@ 0.2% at 30 and 60 DAS	29286	111377	82092	2.80
T8: RDF+ foliar application of FeSO4@ 0.5% at 30 and 60 DAS	29245	107069	77825	2.66
T9: RDF+ foliar application of Borax @ 0.25% at 30 and 60 DAS	29226	113248	84022	2.87
T10: RDF+ foliar application of ZnSO4@ 0.2% + FeSO4@ 0.5% + Borax @ 0.25% at 30 and 60 DAS	29617	118496	88879	3.00

IV. CONCLUSION

The application of RDF along with FYM @ 10 t ha^{-1} registered significantly higher growth parameters noted after harvest of groundnut, the combined soil and foliar application of micronutrients (T_6 andT_{10}) and individual soil application of micronutrients (T_5, $T_3$and T_4) were found statistically comparable. The highest gross returns was obtained with application of RDF along with 10 tonnes of FYM (T_2), whereas, the highest net returns and benefit cost ratio were obtained with the combined soil application of micronutrients (T_6).

Thus, it can be concluded that combined soil application of all micronutrients followed by individual micronutrient application alone found better than foliar application of each micronutrient alone. The highest net returns and benefit cost ratio were obtained with the combined soil application of all micronutrients. However, combined foliar application of all micronutrients proved on par with soil application of micronutrients.

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A Study on Trends and Growth Rates in Area, Production and Productivity of Sugarcane in Kushinagar District of Uttar Pradesh, India

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Abstract— *The study was conducted to know trends in growth rate of area, production and productivity of sugarcane in India and performance of sugarcane crop production of Kushinagar, Uttar Pradesh. The study was based on secondary source of data. Simple statistical tools like compound annual growth rate, percentage methods were used in this study. The study reveals that compound annual growth rate in case of area, production and Productivity showing a positive sign. The compound annual growth rate in area, production and productivity in India is reported an increase of 0.80 percent, 1.73 percent, and 0.92 percent. The compound annual growth rate in area, production and productivity in Uttar Pradesh is reported an increase of 0.43 percent, 1.51 percent, and 1.06 percent, respectively. The compound annual growth rate in area, production and productivity in Kushinagar district is reported that -0.15 percent, 2.72 percent, and 2.87 percent, respectively. The area and production of crop is showing a fluctuating trend because there are many factors which is responsible sugarcane cultivation like monsoon conditions, government price polices etc.*

Keywords— Trends, Compound annual growth rate, Production, Productivity, Sugarcane.

I. INTRODUCTION

Sugarcane is important cash crop grown in India. Sugarcane is one of the most important commercial crops of the country and the sugar industry occupies an important place in the economy of our country. Sugarcane crop provides raw material to over 25 other industries and sugar industry is one of the largest agro based processing industry responsible for socio-economic development of rural masses and national economy of our country. In the current day rural economy set up sugarcane cultivation and sugar industry has been focal point for socio-economic development in rural areas by mobilizing rural resources, generating employment and higher income, transport and communication facilities.

India is 2nd largest sugarcane producer in the world with the production of 494.22 million metric tons the area of 5.88 million hectare Presently sugarcane is grown in an area of 2.73 million hectare (45.12 percent) and production 225.22 MT (44.78 percent|) among the sugarcane growing countries of the world Uttar Pradesh has 1st position in sugarcane area 45.12 percent in the country, followed by Maharashtra, Karnataka, Bihar, Gujarat, Tamil Nadu, Madhya Pradesh, Haryana, Punjab, Uttarakhand, Andhra Pradesh. (https://sugarcane.dac.gov.in/ 2022-23). Uttar Pradesh is the largest production of sugarcane in India. The climatic condition of Uttar Pradesh is ideal for sugarcane cultivation. Sugarcane industry is an important industry of Uttar Pradesh and is the main source of almost 35 lakhs farming families of the province. The province has a total of 157 established sugar mills from where at present season 2023-24 total 118 sugar mills are operational. Total sugarcane area of province is 2.73 million hectare and sugarcane productivity is 104.78 tonne per hectare.

The compound growth rate of area, production and productivity of sugarcane in Orissa during the period 1995-96 to 2005-06 for the state were -1.43(NS) per cent, 0.06 (NS) per cent, 1.86 (MS) per cent. **(Rout *et al.* 2016).** The trend in growth models on area, production and productivity of sugarcane crops in coastal Andhra region of Andhra Pradesh state for the period of 1973-74 to2012-13. They observed that quadratic function was the best fitted model for area and production where as linear function for productivity. And the results revealed that area, production and productivity of sugarcane crop would be increased during their study period **(Greeshma *et al.* 2017)**. A time series data from 1970-1971 to 2014-15 (45 year) of major sugarcane producing states Uttar Pradesh and Maharashtra in India was used. It is revealed from the results that area, production and productivity of sugarcane is increasing at the rate of 1.20 per cent, 2.27 per cent and 1.20 per cent respectively in Utter Pradesh and 4.10 per cent, 3.80 per cent and0.2 per cent respectively in Maharashtra. At India level area, production and productivity grew at the rate of 1.6 per cent, 2.5 per cent and 0.9 per cent respectively in India, **(Kumar and Singh 2018).** Analyzed sugarcane cultivation trends in India and Haryana from 1971 to 2018. It finds an overall increasing trend in India, with Compound Annual Growth Rates (CAGRs) of 1.52 percent, 0.84 percent and 2.37 percent, for area, production, and productivity respectively. In Haryana, the trend is decreasing, but production and productivity are increasing, **(Nisha *et al*. (2020**).The trend of sugarcane productivity in Maharashtra was found to be stagnant between 1.0 to 3.0 percent. The result of decomposition analysis indicates a relatively more important contribution of area rather than increase in the production. The result of the Instability analysis revealed that the level of instability in the area, production and productivity of sugarcane increased drastically in Maharashtra. (**Gupta and Badal (2021).**

II. MATERIALS AND METHOD

2.1 Compound growth rate analysis:

In order to access growth in credit to different purposes compound growth rates will be worked out. Compound growth rates will be computed by using exponential function of the form.

$$Yt = A\ B^t e^{ut} \qquad (1)$$

Where,

Yt= Credit dispersed during time t

A= Y in the base year

T= Time period

ut= Error term

B= 1+g

g = Growth rate.

By taking the logarithm, equation (1) was reduced to the following form

$$LogYt = LogA + (Log\ B)t + ut \qquad (2)$$

Where Log A and Log B were the parameters of the function obtained by ordinary least square method (OLS).

Defining, Qt = log Yt

t = time period

a = log A and b = log B

Equation (2) can be written as follows

$$Qt = a + bt + ut \qquad (3)$$

Once the above equation is estimated, g can be computed as:

$$g = (Antilog\ (b) - 1) \times 100 \qquad (4)$$

III. RESULT AND DISCUSSION

3.1 Compound annual growth rate (CAGR) of sugarcane in India:

Table 1 indicates the compound annual growth rates for area, production, and productivity for all sugarcane in India.

TABLE 1
YEAR WISE AREA, PRODUCTION AND PRODUCTIVITY OF SUGARCANE IN INDIA (2001 TO 2022)

Year	Area (in 000 ha)	Production (in 000 tonne)	Productivity (in 000 tonne/ha)
2001	4.32	295.96	68.50
2002	4.41	297.21	67.37
2003	4.52	287.38	63.58
2004	3.93	233.86	59.38
2005	3.66	237.09	64.75
2006	4.20	281.17	66.93
2007	5.15	355.52	69.03
2008	5.06	348.19	68.88
2009	4.42	285.03	64.55
2010	4.17	292.30	70.02
2011	4.88	342.38	69.25
2012	5.04	361.04	71.63
2013	5.00	341.20	68.24
2014	4.99	352.14	70.57
2015	5.07	362.33	71.47
2016	4.93	348.45	70.39
2017	4.44	306.07	69.00
2018	4.74	379.90	80.20
2019	5.06	405.42	80.10
2020	4.60	370.50	80.54
2021	4.85	405.40	83.59
2022	5.15	431.81	83.85
Total	102.59	7320.35	1563.07
CGAR %	0.80	1.73	0.92

Sources: dacnet.nic.in

It shows that the respective rates for area, production, and productivity were 0.80 percent, 1.73 percent, and 0.92 percent. The chart indicates that in 2007 and 2022, the largest area was 5150.00 thousand hectares, and in 2015, it was 5070.00 thousand hectares. 405.42 MT in 2019 and 83.85 MT in 2022 were the highest production and productivity, respectively, while 83.59 MT in 2021 and 431.81 MT in 2022 were the highest productivity.

3.2 Compound annual growth rate (CAGR) of sugarcane in Uttar Pradesh:

Table 2 indicates the compound annual growth rate for the area, productivity, and production of all sugarcane in Uttar Pradesh.

TABLE 2
YEAR WISE AREA, PRODUCTION AND PRODUCTIVITY OF SUGARCANE OF UTTAR PRADESH (2001 TO 2019)

Year	Area (in 000 ha)	Production (in 000 tonne)	Productivity (in 000 tonne/ha)
2001	1.99	129266.70	65.12
2002	1.97	116483.40	58.99
2003	2.01	115418.90	57.39
2004	1.94	106067.50	54.72
2005	2.04	117982.00	57.98
2006	2.15	120948.00	56.28
2007	2.03	112754.00	55.54
2008	1.95	118715.60	60.73
2009	2.16	125469.90	58.20
2010	2.25	133949.40	59.63
2011	2.18	124665.30	57.21
2012	2.08	109048.00	52.33
2013	1.98	117140.00	59.25
2014	2.13	120545.00	56.73
2015	2.16	128819.00	59.58
2016	2.21	132427.68	59.87
2017	2.23	134688.62	60.45
2018	2.14	133061.42	62.15
2019	2.17	145385.00	67.03
2020	2.18	178342.00	81.80
2021	2.18	177438.42	81.38
Total	44.13	2698615.84	1282.36
CGAR %	0.43	1.51	1.06

Sources: dacnet.nic.in

It shows that the area, productivity, and production all had compound annual growth rates of 0.43 percent, 1.51 percent, and 1.06 percent, respectively. According to the table, the largest area was 2.25 thousand hectares in 2010 and 2.23 thousand hectares in 2017. 2020 and 2021 show the highest output and productivity levels, respectively, of 178.34 MT and 177.43 MT. In 2020, 81.80 MT and 81.38 MT were the highest productivity levels.

3.3 Compound annual growth rate (CAGR) of sugarcane in Kushinagar:

Table 3 provides an examination of the compound annual growth rate for the acreage, productivity, and production of all sugarcane in Kushinagar.

TABLE 3
YEAR WISE AREA, PRODUCTION AND PRODUCTIVITY OF SUGARCANE OF DISTRICT IN KUSHINAGAR (2010 TO 2021)

Year	Area (in 000 ha)	Production (in 000 Tons)	Productivity (in 000 tons/ha)
2010-11	73.13	3763.65	5.15
2011-12	72.23	3758.61	5.20
2012-13	70.22	3998.09	5.68
2013-14	99.10	5923.25	5.98
2014-15	70.10	4217.90	6.02
2015-16	71.89	4251.06	5.91
2016-17	71.89	4689.97	6.52
2017-18	71.89	5164.49	7.18
2018-19	70.89	5450.09	7.69
2019-20	71.89	5445.76	7.58
2020-21	71.89	4923.26	6.84
Total	815.12	51586.94	69.75
CAGR %	-0.15	2.72	2.87

Source: dacnet.nic.in

It shows that the area, productivity, and production all had compound annual growth rates of -0.15 percent, 2.72 percent, and 2.87 percent, respectively. The chart indicates that in 2013–14, the highest area was 99.10 thousand hectares, followed in 2010–11 by 73.13 thousand hectares. 2013–14 saw the highest output of 5923.25 MT, which was followed by 2018–19's 5450.09 MT. Similarly, 2018–19 saw the highest productivity of 7.69 MT, which was followed by 2019–20's 7.58 MT.

IV. CONCLUSION

The growth rate of area, production and productivity of sugarcane in India and Uttar Pradesh for the last 22 years were witnessed to be positive, significant and showing an increasing trend over time. It revealed that the production of sugarcane increases mainly due to expansion of the area under sugarcane cultivation and slight improvement of productivity by the adoption of advanced cultivation practices and diversification of cultivated variety. In case of Kushinagar district, the compound annual growth rate in area was negative trend but production and productivity was positive. It implies that farmers should need to pay adequate attention to adopt improved production technologies and advanced management to address the problems of fluctuation in sugarcane production.

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Climate Change Implications on Soil Health and Agronomical Interventions to Increase Soil Carbon Sequestration under different Landuses

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***Abstract*—** *Healthy soil is the crucial factor required to meet the global demands for food and fibre for the burgoining population. However, global food security is threatened by climate change impacts. Climate change, variability, and mismanagement or misuse of resources lead to soil degradation and vulnerability. Hence, sustainable soil management aims for the services of soil to be maintained without significantly impairing the soil functions that enable those services or biodiversity. Sequestering higher carbon in soils will help the soil increase its resilience to climate change in the long run. Therefore, every step towards sustainable soil health management in the climate change scenario should focus on soil carbon sequestration. The soils under different land use systems have various carbon sequestration potential. Adoption of the best management practices like conservation tillage (minimum, zero/no-till), balanced fertilization, green mulching, crop residue management, cover cropping, organic manures and in-situ soil and moisture conservation measures in agricultural lands can improve the carbon sequestration potential. The amount of carbon stored in forest soils is often greater than aboveground in living and dead plant biomass. Managing forests to optimize carbon sequestration is also essential to increase the carbon in forest soils. Carbon sequestration is the global mission achieving this is possible only through local vision involving the farmers, researchers and common public as agricultural/ forest soils and trees have the tremendous potential to sequester atmospheric carbon. Focus on soil health management to mitigate the climate change impacts is indispensable to have a sustainable ecosystem with high biodiversity.*

***Keywords*— climate change, soil health, soil degradation, soil carbon sequestration, sustainable soil management, land use systems, soil organic carbon, carbon loss, conservation tillage.**

I. INTRODUCTION

Soil is a storehouse of nutrients and water essential for crop production, hydrological cycle and atmospheric gas exchange. It is the foundation for plant establishment, growth, agriculture, and forest and livestock production. The soil's biodiversity and abundance of biological activity are more incredible than in any other terrestrial ecosystem. Soil contributes about 98% of our food directly or indirectly (Lal et al., 2021). Climate change, variability, and mismanagement or misuse of resources lead to soil degradation and vulnerability. The SOC pool in 1 m depth of soil is 30 tons ha^{-1} in arid regions, whereas in organic soils of temperate areas, it is 800 tons ha^{-1}. But it is also an alarming message that most agricultural soils have lost 30 to 75% of the soil organic carbon pool that accounts 30 to 40 t C ha^{-1}. This carbon loss is more significant in soils prone to accelerated erosion due to human activities, resulting in soil quality degradation and productivity decline. The optimum organic carbon level is necessary for the soil to hold water and nutrients, decrease soil erosion and degradation risks, improve soil structure, and provide energy to soil microorganisms.

In contrast, soils have more potential to store carbon than other terrestrial ecosystems as agriculture, deforestation, and other anthropogenic activities have reduced their organic carbon content. Practices like intensive agriculture, high chemical input farming, and clean cultivation have drastically depleted the soil's organic carbon content and adversely affected soil health. The critical limit of SOC concentration for tropical soil is 1.1%, but they have a very low organic carbon content level of 0.1 to 0.2 %. Accomplishing the critical organic carbon content level in these regions will be arduous for farmers and scientists. But agricultural soils have the potential to sequester carbon to their original capacity. The effect of carbon sequestration is more prominent in degraded soils regarding soil health improvement. Soil C sequestration is an effective food and nutrition security strategy through soil quality improvement. SOC sequestration in soils is an effective climate change mitigation option (Lal 2004), and the 4 per 1000 initiative suggested that 20–35% of global anthropogenic greenhouse gas emissions could be reduced by increasing global SOC stocks in the top 40 cm by 0.4% per year (Minasny et al. 2017). Therefore, every step towards sustainable soil health management in the climate change scenario should focus on soil carbon sequestration.

II. SOIL HEALTH

Soil health is the state of the soil being sound in physical, chemical, and biological conditions, having the capability to sustain the growth and development of plants. Soil is one of the most precious resources has a vital role in the water cycle. Healthy and biologically active soil are what we need for healthy food and clean water.

2.1 Climate change implications on soil:

Climate change is an essential factor in the planning and management of natural resources. Climate change, land degradation and biodiversity loss made the soil one of the world's most vulnerable natural resources. Projected temperature changes and rainfall patterns are likely to affect the SOC stock directly and indirectly. Directly, the temperature and moisture regime will affect microbial decomposition. Indirectly, it will affect the crop growth, productivity, above and below-ground biomass. Due to global warming, rainy days are expected to decline in many regions with more extreme events, and evaporation and transpiration rates are projected to increase. These changes may reduce the soil moisture availability for plant growth. The higher temperatures will also accelerate the rate of soil organic matter decomposition (mineralization), especially near the soil surface, which will affect the soil's potential capacity to sequester carbon and retain water. Many experiments showed that an increase in soil temperature would result in a significant loss of organic matter in agricultural and forest soils (Heikkinen et al., 2013; Melillo et al., 2017).

Higher soil temperatures increase the microbial decomposition and control of SOM storage in soil. Moist but well-aerated soils support microbial activity, and decomposition rates decrease as soils become drier. Flooded/submerged soils have lower rates of organic matter decomposition due to restricted aeration and thus, with very high amounts of soil C. High precipitation will transport the carbon down to the soil profile as dissolved or particulate organic matter. During drought, SOM decomposition may initially decrease but subsequently increase after rewetting. Soil physical properties are crucial in deciding the soil response or resilience to climate change. The inherent soil property, like texture, is resistant to change or changes very slowly over time, but soil organic carbon content, structure, CEC, nutrient availability, soil biodiversity and pH are more easily affected by climate and management practices. The proper soil management practices that keep the ideal soil's physical properties are inevitable to deliver soil ecosystem services, such as storing water, supplying nutrients to plants, sequestering carbon and reducing greenhouse gas emissions. Understanding these properties will enable the farmers to understand the climate change effects and mitigate its impacts.

2.2 Healthy soil:

Soil is no more an inert medium to physically support plant but a living entity has "health" that nourishes billions of lives in it. Soil system always responds to the way it has been treated and managed. A good soil management programme would involve the practices and techniques that augment the soil health by increasing key soil properties, recycling nutrients, sequestering carbon, and encourage soil biological population to flourish and diversify to keep the ecosystem functioning well. It also helps in absorbing, retaining rainwater for use during dry periods and draining the excess rainwater, filtering and buffering water to remove any toxic pollutants. Once soil health is lost it is very tough to regenerate, globally soil health is maintained with five soil health principles and each one is equally significant. Farmers can even customise the techniques according to their region, crop cultivation practices and feasibility to achieve the objective of these basic principles.

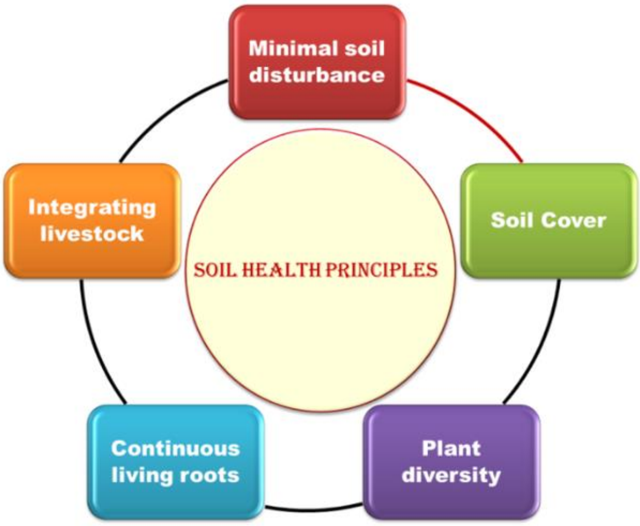

FIGURE 1: Principles of Healthy soils

2.3 Sustainable Soil Health Management:

Sustainable soil management aims the supporting, provisioning, regulating, and cultural services of soil are maintained without significantly impairing either the soil functions that enable those services or biodiversity. The four types of ecosystem services and the soil functions explained are (FAO, 2015)

- Supporting services - primary production, nutrient cycling and soil formation
- Provisioning services - supply of food, fibre, fuel, timber and water; raw earth material; surface stability; habitat and genetic resources
- Regulating services - water supply and quality, carbon sequestration, climate regulation, control of floods and erosion
- Cultural services - aesthetic and cultural benefits derived from soil.

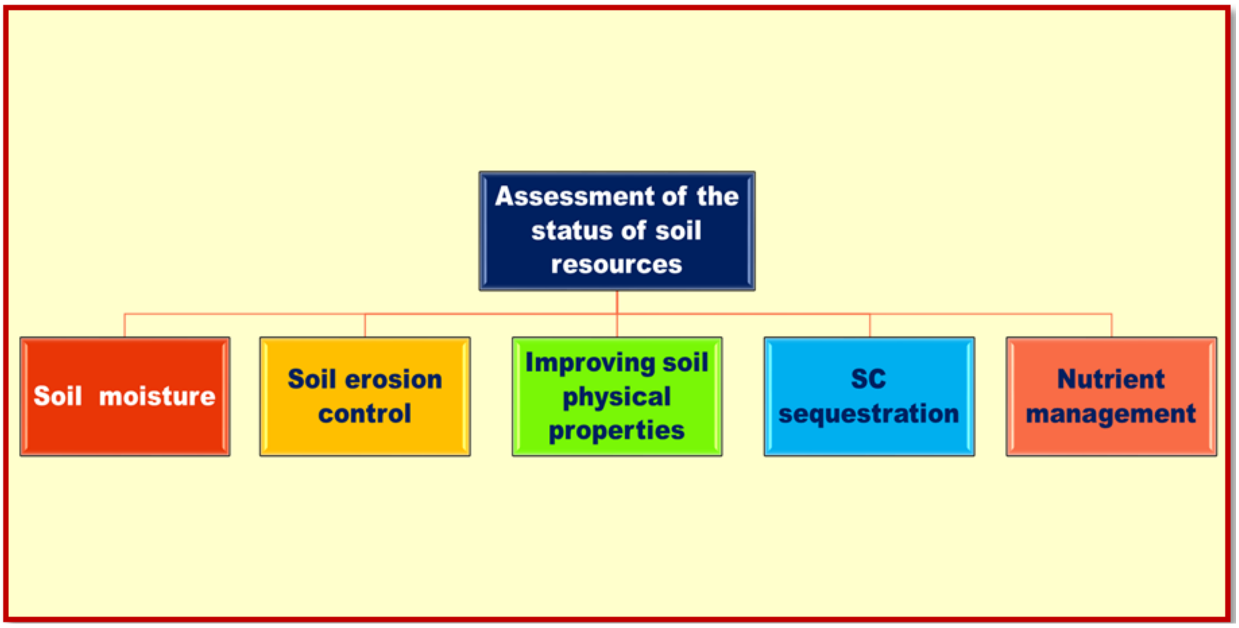

FIGURE 2: Sustainable soil management strategies

2.4 Soil Management interventions for carbon sequestration:

Carbon sequestration in soils will contribute directly to climate change adaptation and mitigation. This will also make agricultural production systems more sustainable; increase the overall resilience of agricultural ecosystems; and maintain the ecosystem services of soils. Sustainable soil and land management practices adapted to the local biophysical and socio-economic conditions can enhance the interactions among soil, water, plants and livestock which can prevent, slow or stop soil degradation as the impacts of climate change (Lal, 2013). The ninth principles from the World Soil Charter (FAO, 2015) say that soils that degradated can, in some cases, have their core functions and contributions to ecosystem services restored by applying appropriate rehabilitation techniques. This increases the area available to provide services without necessitating land-use conversion. Many already proven soil management practices can help farmers to mitigate the adverse effects of increasing weather variability and climate change. The widespread adoption of these practices can contribute to the global carbon sequestration and maintain the soil health.

The soil carbon sequestration depends on a number of factors like

1. **Abiotic** - clay content, mineralogy, structural stability, land slope, soil moisture and temperature regimes
2. **Biotic –** land use, management practice, activities of soil organisms

The best management practices should consider all these biotic and abiotic factors for improving the efficiency of any land use to store the soil carbon.

III. CLIMATE CHANGE AND LAND USE CHANGES

Several land uses are prevalent in the earth that are often changing due to increasing population pressure and climate change. The dynamics of these changes are complex to understand and cause the degradation of natural resources. Many processes are responsible for the rapid land use changes over space and time. Due to increasing population pressure in the hilly regions, deforestation has increased, bringing the forest land under annual cultivation/habitat construction. It also exerted pressure on farmers to go for intensive cultivation without leaving time for green manuring or a fallow period to replenish the soil. These changes have resulted in soil and water quality degradation. Climate change and inadequate rainfall distribution also brought many fertile agricultural lands under real estate. Hence, deriving land use-specific management options to enhance the soil carbon sequestration potential is necessary to mitigate future climate change impacts on soils.

3.1 Improving soil carbon sequestration potential of Agricultural land use:

Some of the best management practices for agricultural lands to improve the carbon sequestration potential are listed below

- Organic Manure application
- Balanced fertilization
- Conservation tillage (minimum, zero/no-till)
- Mulching
- Crop residue management
- Cover cropping

3.2 Organic manure application:

The application of organic manure add carbon and other nutrients in the soil. The addition of organic manures in agricultural lands increases SOC stocks. Carbon stocks in the world at 0–20 cms depth improved 240–460 Kg C $ha^{-1}yr^{-1}$ after ten years of manure addition (Gattinger *et al.,* 2012). Further, a 30% increase in SOC at plough layer (0-15 cm) due to organic manure addition (Zavattaro *et al.,* 2017). Manure application could further add SOC concentration due to added organic C inputs in manure (Zhao *et al.,* 2014). Continuous addition of manure for four years, a 25% C was stored in the soil carbon pool (Eghball, 2002).

3.3 Balanced Fertilisation:

The Green Revolution transformed India into self-sufficient in food grain production; no other activity had such an immense impact on the country's economic development. The fertilization approach was one of the best field management practices to achieve high crop yields in intensive agriculture with high yielding varieties. But recently, farmers forgot the 4:2:1

ratio of NPK application and urea as a nitrogen fertilizer is used much more than the recommendation. Indiscriminate application of fertilizers also degrades the soil quality (Lin et al., 2014). Hence balanced nutrient application combining chemical fertilizers and organic manures will help enhance microbial activity and carbon sequestration.

3.4 Conservation Agriculture:

Intensive and conventional agricultural practices challenged agriculture's sustainability through soil degradation, declining soil organic matter, loss of soil biodiversity, depletion of groundwater, and greenhouse gas (GHG) emissions (Parihar et al., 2018). Decreased land availability and increased cropping intensity, urging the farmers to remove the crop residues from the field immediately after harvest. Intensive cultural operations with farm equipment break the natural soil aggregates and modify the soil structure. This practice leaves the soil surface bare and highly prone to erosion and soil degradation (Doraiswamy et al., 2007). Minimum soil disturbance and maximum crop residue returns will improve soil organic carbon (SOC) storage and maintain soil health. Conversion to no-till practice on the lands under corn-soybean cropping rotation could sequester about 2% of the annual anthropogenic emissions of CO_2 emissions in the United States (Bernacchi, Hollinger, & Meyers, 2005). Conservation agriculture supports soil in adapting to climate change by improving its resilience against extreme climatic situations (Maity et al., 2021).

3.5 Mulching:

Mulching with organic materials can effectively change the soil microclimate, enhance microbial activity, and release soil nutrients to plants (Vogel et al. 2015). Mulching will change the nutrient cycle and energy flow between the soil and plants and alter SOC dynamics. It improves soil properties by adding carbon and nutrient sources through the decomposition of organic matter; and directly increases SOC.

3.6 Crop residue management:

Crop residues contribute to the maintenance of soil organic carbon (SOC), a key component of soil fertility and soil-based climate change mitigation strategies. Crop residues are essential for maintaining soil organic matter content and sustaining crop production. They are also a vital energy source for soil macro- and microorganisms, stabilizing soil aggregates, enhancing nutrient cycling, and improving soil physical properties (Canqui and Lal 2009). In regions with >20°C annual temperature decomposition rate of crop residue is higher than in the cooler regions. Hence, a threshold level of residue retention in soils of the tropics to increase the SOC pool should be determined. Crop residue retention in fields should be an integral part of crop cultivation to increase the soil's organic carbon level

3.7 Cover cropping:

Cover crops are an important soil carbon sequestration strategy usually used as green manure and ploughed into the soil before the subsequent crop is sown important cover crops belong to cereals, brassicas, and legumes to fit almost any cropping system. Apart from reducing the erosion and carbon loss cover crops enhance the growth of soil organisms, which increases soil carbon levels over time. Nine years of cover crop addition contributed 10–20 Mg C ha^{-1} organic carbon in soils compared to no cover crop experiment (Chahal et al., 2020). Cover crops should be fast growing and produce higher biomass for serving both the purpose of erosion control and soil carbon sequestration.

3.8 Carbon sequestration in forest soils:

Forests are a major terrestrial ecosystem which occupies 30–43 % of the world's land surface. They serve the purpose of habitats for wildlife, clean water and carbon storage, and climate mitigation. Forest biomass is the major pool of green carbon, and the total amount is estimated at approximately 359 billion tons (Allen et al. 2010). Forest soil is the largest carbon pool among the soils of various land uses. Overall, the forest ecosystems store twice as much carbon as the atmosphere. The carbon sequestration and the role of forests in curbing climate change are remarkable. Worldwide, forests store approximately 47% of total global carbon (Malhi et al. 2002). The carbon sequestered in soil can stay in the ground for a long period of time. Carbon is released due to microbial decomposition for energy. This process depends largely on soil drainage, climate, natural vegetation, and soil texture.

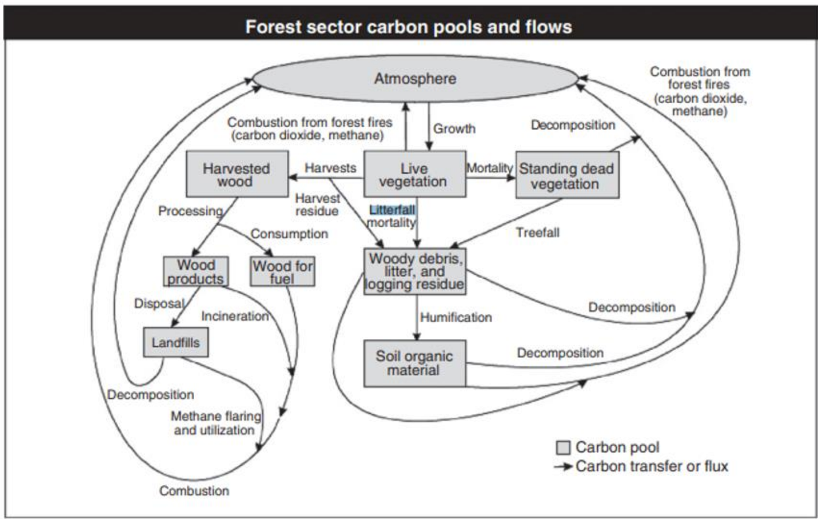

FIGURE 3: Forest carbon sequestration cycle

Source: EPA (2010).

There are many approaches to increase the carbon content of forest soils

1. The most obvious approach is afforestation: Simply planting trees on a previously unforested site/wastelands
2. Proper forest management to increase the biomass
3. Extending the harvest rotation for the joint production of carbon and timber
4. Carbon credit system
5. Forest fire can accelerate carbon loss from soils, hence proper fire management system should be derived and executed

Management practices that maintain forest cover, create forests where they did not exist previously (afforestation) and avoid drainage of systems with deep organic soils (which contain substantial carbon stores), are likely to have the best results for keeping carbon in forest soils.

3.9 Involving farming community and public in carbon sequestration:

The farming community's involvement is essential in achieving the potential soil carbon sequestration rate. Government initiatives to sequester the soil carbon will motivate the farmers to recognize the importance of carbon in sustainable soil health management

- **Incentives:** Farmers applying all best management practices to improve the soil carbon have to be given incentives such as money or inputs
- **Priority in subsidies and insurance:** The farmers who sequester carbon on their farm should be given preferences in subsidies and crop insurance claim
- **Recognitions and awards:** Farmers should be recognized with awards and certificates for their contribution to carbon sequestration
- **Community Carbon parks:** The establishment of village level carbon parks with carbon sequestering potential and fast-growing tree and grass species in community lands
- **Convergence with Corporate social responsibility:** Corporate sector can adopt a village under CSR to improve the carbon status of degraded land
- **Carbon tax:** Farmers who are not improving the carbon status of their land should be taxed
- **Creating awareness:** Awareness to sequester the carbon in soil and farm through mass awareness and skill development programmes.

IV. CONCLUSION

Soil health management will continue to play a prominent role in any land use systems and will be influenced by climate change. Healthy soil is more resilient against fluctuations in climatic parameters. The resiliency of the soil ecosystem needs to be enhanced to cope with climatic variations. Building and improving soil health through SCS in agricultural and forest soils will ensure continued productivity, enhance farmers' incomes, and holistically promote food security. Building and maintaining healthy soil is not easy, especially in the arid and semi-arid regions. Carbon sequestration is the global need to combat the impacts of climate change through greenhouse gas emissions. Achieving this global mission is possible only through local vision involving the farmers, researchers and common public as agricultural/ forest soils and trees have the tremendous potential to sequester atmospheric carbon. Focus on soil health management to mitigate the climate change impacts is indispensable to have a sustainable ecosystem with high biodiversity.

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Pomacea Canaliculata (Golden Kuhol) Abundance in Rice Duck Pig Farming System

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Abstract— *The major purpose of this study is to determine the abundance golden apple snail in rice duck pig farming system. Weekly mean abundance of golden apple snail on the rice field fluctuates during the first four weeks of the experiment, gradually decreased during the succeeding weeks until the final week of the experiment. The graphical representation of each weekly mean per treatment shows the obvious decreasing significance of the golden apple snail in the rice field. Stocking densities of ducks decreased every week starting from week 4 of the experiment. The cause is not clear, but the weather can be considered as one of its causal factors since the experiment was done during rainy season. However, even if the stocking densities of ducks decreased, the abundance of golden apple snail decreased during the final weeks. The presence of duck in the rice field is effective in minimizing the abundance of golden apple snail. Distributed ducks in the rice field fed on the golden apple snails that are present in the soil which resulted to the decrease and elimination of the snails. Through this event, the field doesn't need the application of any type of insecticides because the pests were reduced.*

Keywords— Golden Apple Snail, Rice-Duck-Pig Farming System, Stocking Density.

I. INTRODUCTION

In most of the tropical countries including the Philippines, farming is one of the most common types of work. As a matter of fact, agriculture in general, plays big part in our country's economy. Agriculture involves 40% of Filipino workers, and it contributes an average of 20% to the gross domestic products. The Philippine archipelago consists of mostly sea, but the land area suitable for farming is quite impressive having 47% of the total land area. Farming is also popular especially in rural areas within the country and one of the major sources of income of a simple Filipino family.

There are different kinds of farming depending upon what type of resources the place is capable of cultivating. As technology grasps its big leap towards improving and innovating, the people must also cope-up with its pace. That is why farming methods also come up with innovative ideas. One example of innovative farming is rice duck farming.

Rice duck farming is an integrated type of farming technology. It is suitable for small scale farmers to produce organic rice in low-cost. It is very suitable for the Philippines because most of the farmers belong to the lower sector of the society. Ducks eat harmful insects and weeds averting the use of chemical pesticides and manual weeding in the rice field. They also acquire nutritious diet from eating insects and weeds in rice fields. The manure of the duck act as a natural fertilizer to the rice crop preventing the use of chemical fertilizers, the continuous movement of ducks in the rice field provides natural stimulation and aeration which increases the availability of nutrients like nitrogen, phosphorous, and potassium to the rice crop. Rice-duck technology causes the reduction of emission of methane gas from rice field contributing to reduce the global warming.

Golden apple snail (*Pomacea canaliculata*) is a common freshwater snail and a notorious agricultural pest in the Philippines and other countries in Asia. It was introduced from Florida and Latin American to Taiwan in the early 1980s to start an escargot industry (Mochida 1988, 1991; Naylor 1996). Concerted efforts have been undertaken to annihilate them but they still persist and even spread naturally and intensively. Since this snail is ecologically important, persistent and possesses attributes of a bio monitor, they are big enough to provide sufficient material (soft tissue) for analyses. They are easy to handle, collect, and culture; they are abundant, and sedentary; they can survive for a long time without food, and live long; they can be found in almost any freshwater ecosystem in many countries. The need for an extensive study for ecological management is necessary because of these things. They damage direct wet-seeded rice and transplanted rice up to 30 days old. Once the rice plant reaches 30−40 days, it will become thick enough to resist the snail. If no control measure is taken, they can completely destroy 1 m^2 of field overnight. This damage could lead to more than 50% yield loss.

Generally speaking, the use of duck in farming is widely acceptable method to use in rice farming. The use of ducks as an approach in eliminating pests such as a golden apple snail could benefit the rice field itself and it could also be beneficial in nature in many ways.

II. MATERIALS AND METHODS

The study was conducted at Future Rice Farm, Philippine Rice Institute (PhilRice), Barangay Maligaya, Science City of Muñoz, Nueva Ecija Philippines. Fence was installed using mesh net and bamboo post, fence is a requisite to ward-off astray animals that may hurt the ducks and prevent them from escaping. The total measurement of area is 486.98 m^2 and divided in to 3 treatments with 3 replications. The paddy rice field was rotovated, plowed and harrowed once. RC298 variety was used and classified as good seed. Using cloth bag, seeds were wrapped and soaked for 24 hours, after soaking, seed were planted in the seedling plots with seedling density of 50gm/sq.m. After 2 weeks, seedlings were transplanted to the paddy rice field in a straight row with planting distance of 30cm x 15cm, 2 seedlings per hill. Continuous irrigation was used with a depth of 10-15cm, organic fertilizer was applied using animal manure (ducks and pig), sugarcane, bagasse and hay. Pig slurry was applied to paddy rice field twice a week from week 1 to week 8 in 12 plots.

A total of 54 ducklings was used in the experiment and distributed into respective treatments: (T1 – Four (4) ducks, T2 – Six (6) ducks, and T3 – Eight (8) ducks). 14-day old ducks were released into the paddy rice field after two weeks from transplanting of rice plant. Ducks stayed in the field for 56 days. 1 litter of water with 5 tbsp. of sugar was used as medication and biologics of ducks.

The number of golden apple snail in each plot was counted and recorded and was done weekly. A definite of 4:00 pm for two hours was spent during the manual counting. As the counting took place in the rice field, ducks still stayed within the plots. The number of golden apple snail counted was tabulated immediately after the said activity.

III. RESULTS AND DISCUSSION

In every treatment, it was observed an obvious decrease in the abundance of golden apple snail, however, there is also a dramatic increase in its abundance that is most visible during the second and the fourth week. The increase during the second week of the experimental treatment was due to the fact that the installation of the ducks in each plot was done on August 23, 2019 after the second counting of golden apple snails. That is the reason why they were not able to consume much golden apple snails during the second week of the experiment. Aside from that, it is also considerable to indicate that some of the golden apple snails are of large sizes which cannot ingest by the ducks. During that time, the ducks are just 14-day old. The sudden increase in the number of golden apple snails during the fourth week was because of the inability of the young ducks to eat much golden apple snails on the rice fields especially the matured ones during the second week. Due to this setup, the female matured snails laid its eggs in bright pink ranging from 25 to 500 eggs per batches with the hatching time of 10 to 15 days (Halwart, 1994). The eggs hatched the most during the fourth week of the experiment that caused the snail population to increase. After the fourth week of the experiment, the abundance of the golden apple snail gradually decreased until the final week where there is a visible count of eight (8) down to zero (0) in most plots that received Treatment 3.

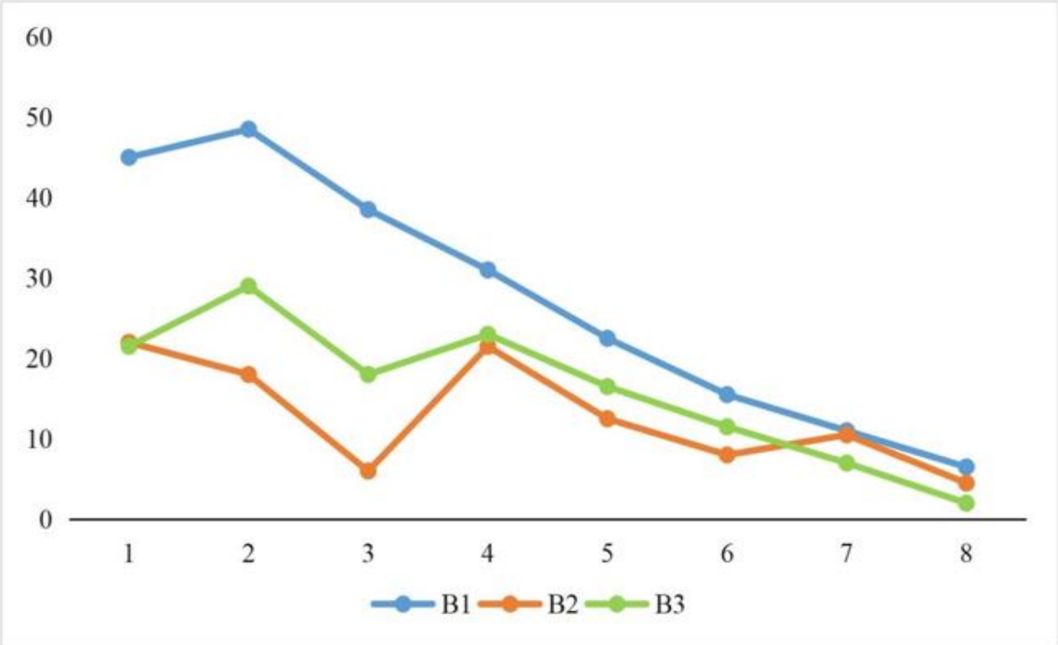

FIGURE 1: Weekly Mean Abundance of Golden Apple Snail for Treatment 1 (4 Ducks)

The graph on Figure 1 shows the average weekly abundance of golden apple snail for Treatment 1 having four (4) ducks inside the rice field. It can be seen in Block 1 (B1) and Block 2 (B2) that the number of snails from week 1 to week 2 has increased while it has decreased in Block 3 (B3). Those gaps in numbers are due to the event where the ducks were setup in week 1 just after the golden apple snail count on the field. As weeks go along, the number of snails in B1 begins to decrease. The graph shows that in B2 and B3 on the other hand, there is an indefinite time when the golden apple snails increased in numbers. Even so, during the final weeks of the setup, all blocks have experienced the decreasing number of snails.

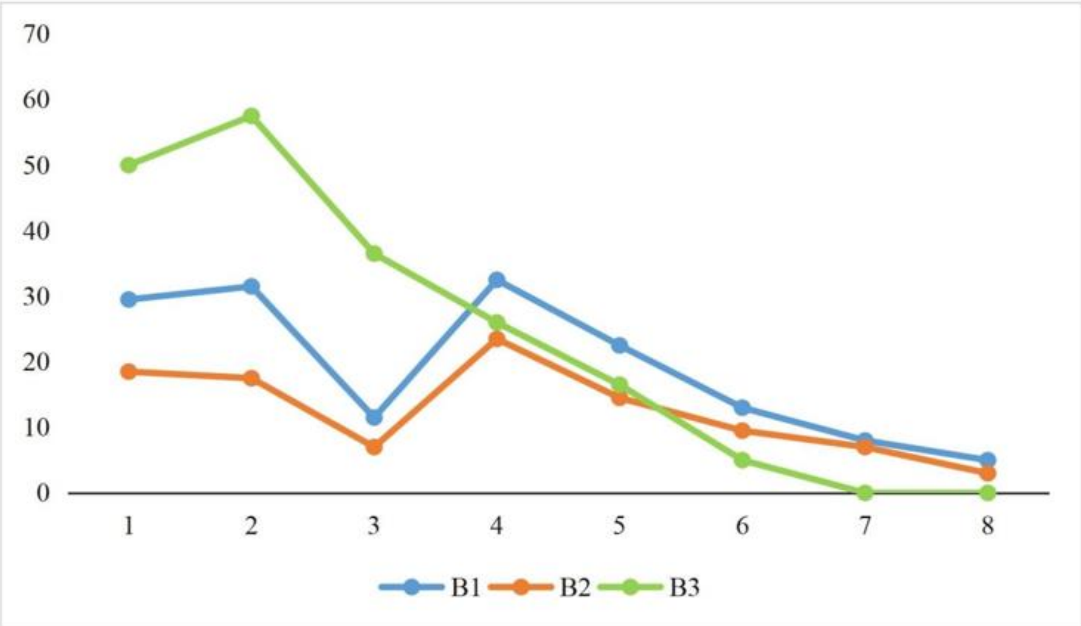

FIGURE 2: Weekly Mean Abundance of Golden Apple Snail for Treatment 2 (6 Ducks)

The average weekly abundance of golden apple snail for Treatment 2 having six (6) ducks inside the rice field is illustrated in Figure 2. It can be seen that the number of snails from the first week to the second week increases in all the blocks with this treatment. It is because during the first week, the ducks are not yet intervened in the field. However, when the ducks were installed, the snail abundance begins to decrease from second week to the third week with B3 having a constant decrease that reached zero (0) during the last two weeks. B1 and B3 had its constant decreasing moment after the fourth week.

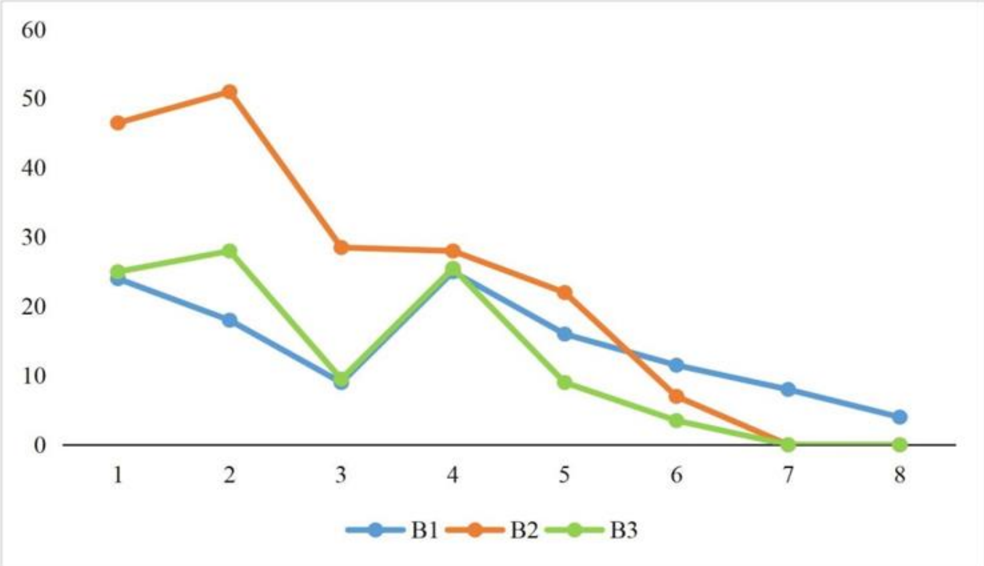

FIGURE 3: Weekly Mean Abundance of Golden Apple Snail for Treatment 3 (8 Ducks)

The graph on Figure 3 reveals the average weekly abundance of golden apple snail for Treatment 3 having 8 ducks inside the rice field. It can be seen that in B1, the number of snails from week 1 to week 3 continuously decreases. In B2 and B3 however, there is an increase in the abundance of snails from the first week to the second week. During week 1, there were no ducks yet in the field resulting to the snails to reproduce. There is also a sudden increase of snails from week 3 to week 4 because of the continuous hatching of its eggs. Even so, as weeks go by, the number of snails in all blocks begins to decrease, with B2 and B3 reached zero (0) snail visibility on the field during the final two weeks of the experiment.

The stocking density of ducks is one of the most important components of the experimental treatment. Echoed by the general objective of the study, the abundance of golden apple snail in the paddy rice field will be determined with the presence of ducks on the field. Table 4 presents the data for the effect of varying duck stocking densities on the mean weekly decrease of abundance of golden apple snail in three (3) different treatments.

TABLE 1
THE EFFECT OF VARYING DUCK STOCKING DENSITIES ON THE MEAN WEEKLY DECREASE OF ABUNDANCE OF GOLDEN APPLE SNAIL

Treatment	Block	Mean[a]
4 Ducks	1	5.5
	2	2.5
	3	2.786 ***3.595***
6 Ducks	1	3.5
	2	2.214
	3	7.143 ***4.286***
8 Ducks	1	2.857
	2	6.643
	3	3.571 ***4.357***

[a] Grand means are italicized and marked in bold.

The grand means marked in italic and bold represent the average decrease of the abundance of golden apple snail in three (3) treatments which corresponds to different number of ducks. The estimated average decreased is dependent to the number of ducks present in the field. Only a slight change can be observed in the difference of the grand means of each treatment, it is because only a little number of ducks was added in the second and third treatment respectively. Also, there is a significant change on the stocking density of ducks particularly during week 4 to 8 whereas during these weeks, the location of the experiment experienced rainy season. During these times, ducks have the difficulty to adapt with this kind of weather. As a result, there is a risk in the survival of the ducks on the rice field that causes inevitable deaths among them. Due to the weekly mortality rate of the ducks on the paddy rice field, the abundance of golden apple snail decrease just a little amount from one treatment to another. That is why the grand means or the total average of the weekly decrease of the abundance of golden apple snail is almost the same.

The duck population started to decrease during the fourth week of the experimental setup and it gradually decreases until the final week. It reveals that the duck stocking densities decrease every week. However, the golden apple snail abundance in the paddy rice fields decreases as well from the fifth week until the eighth and final week of the experiment. Thus, even there are deaths among the stock densities of ducks, the abundance of golden apple snail in each block still decreases, as seen on Figure 1, Figure 2, and Figure 3. It is because the ducks also grow as the time goes by, allowing them to consume much snails compared to the first time they were distributed on the field. Furthermore, the ducks that were on the field are the strongest because they were able to adapt on the changing environment where they were released.

The presence of duck in the paddy rice field is effective in minimizing the abundance of golden apple snail. The distributed ducks in the rice field feed on the golden apple snails that are present in the soil which resulted to the decrease and eventually to the elimination of the snails. Through this event, the field did not need the application of any type of insecticides anymore because the pests were reduced. Moreover, the waste products of the ducks act as a natural fertilizer for the rice crop. It is recommended to consider and look closely to the external factors that may affect the experiment, especially those that occurred in nature like weather, temperature, humidity, etc. Also, they must conduct a study about the economic factors which affect the utilization of the rice duck pig farming system.

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Feeding Value of Unfermented and Fermented Corncob

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Abstract**—** *Corncob is a readily available agricultural byproduct, is often underutilized despite its abundance and potential in animal nutrition. This study evaluates the effect of solid-state fermentation on the nutritional composition of corncob to enhance its value as a feed ingredient, particularly for monogastric animals such as poultry and swine. Results indicated that fermentation markedly reduced crude fiber and anti-nutritional factors like phytates, improving digestibility and phosphorus bioavailability. These enhancements indicates that fermented corncob could be an alternative feed resource to conventional feed stuffs, contributing to sustainable livestock production, reduced feed costs, and better utilization of agro-industrial waste. Its incorporation into animal diets aligns with circular agriculture practices and supports resource-efficient feed development. However, the analysis also resulted in reductions in crude protein, fat, and ash content, while calcium levels remained low before and after fermentation, indicating the need for either improved fermentation methods or dietary supplementation to ensure balanced nutrition.*

Keywords**— *Agricultural byproducts, Digestibility, Fermentation, Nutrient composition, Sustainability*.**

I. INTRODUCTION

Corn (*Zea mays*) is one of the major crops in the Philippines, second only to rice in terms of area harvested and volume produced. Corn is harvested year-round; the resulting byproducts faces the ultimate challenge of managing agricultural waste. The corncobs often overlooked and discarded as one of byproducts of corn that is usually disposed improperly. Corncob has a potential feed ingredient used for animal feeding due to its ample supply and 20% corn content in waste products. (Eniolorunda, et al., 2023).

Ochetim (1993) states that when corncobs are accessible, high-energy feed components such as maize can be partially substituted with corncobs; however, the inclusion rate for optimal use and bird performance must be determined. The primary factors hindering the use of corncobs in poultry nutrition are its fibrous composition, elevated fiber levels, low protein as along with lipid and mineral content. The corncob is made up of cellulose, hemicellulose, and lignin. Cellulose is a polymer made of glucose units connected through beta 1,4 bonds. Cellulose is not easily hydrolyzed because of two primary factors. One factor is that cellulose is insoluble in water and forms crystals. Another factor is that cellulose of practical interest is rarely pure but coexists with lignin and hemicellulose in well-defined anatomical structures. In addition, lignin creates a physical barrier around cellulose, rendering it highly resistant to effective breakdown through acid hydrolysis. Lignin likewise decreases the availability of cellulose to cellulase enzymes. Poultry animals are unable to utilize cellulose for energy due to the absence of cellulase: the enzyme that breaks down the beta 1,4 bonds. (Llanes et al., 2022). Recent research also highlighted fermentation as an effective method for improving nutritional value of fibrous feed materials Fermentation not only reduces fiber content and anti-nutritional factors but also enhances palatability and nutrient availability (Sugiharto, 2019). This approach offers a promising strategy to convert waste materials like corncobs into valuable feed resources. Fermentation can transform waste materials into useful ingredients for animal feed by increasing the microbial protein content and lowering anti-nutritional factors.

In light of recent reports indicating that fermentation can improve nutrient values and reduce the fiber content of feed ingredients while also decreasing its anti- nutritional factors (Sugiharto, 2019), it is timely to look into different fermentation methods that would improve the nutrient composition of corncob.

This study aims to determine the chemical composition of corncob and compare the values between unfermented and fermented corncobs.

II. MATERIALS AND METHODS

2.1 Preparation of Unfermented Corncob:

Corncobs were collected from farms in Barangay Sto. Domingo, San Manuel, Pangasinan. The collected corncobs were sun-dried and subsequently ground using a hammer mill equipped with a 4.0 mm mesh screen. A 1 kg sample of the ground corncobs was then subjected to proximate analysis.

2.2 Fermentation Procedure of Corncob:

Corncobs were first weighed and thoroughly mixed with molasses at a rate of 15% based on the total weight of the final mixture. Afterward, 0.4% of a commercial odor-erasing composting microbial powder (OEMC) was added, also calculated relative to the total weight. This microbial powder contained a blend of beneficial microorganisms, including nitrogen-fixing bacteria, which promote decomposition and enhance fermentation efficiency. The prepared mixture was then packed into clean, high-density polyethylene plastic jars, compacted tightly to minimize air pockets, and the jars were sealed securely to create an anaerobic environment. Finally, the sealed jars were stored in a cool, dark location for a fermentation period of 14 days. Following the fermentation process, a 1 kg sample of the fermented corncob was collected and subjected to proximate analysis.

2.3 Experimental Design:

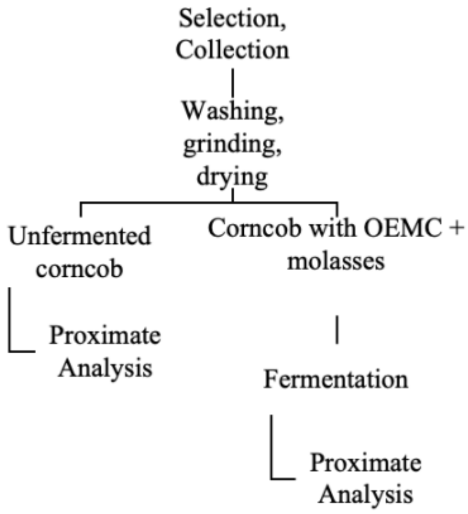

FIGURE 1: Experimental Layout for Proximate Analysis

This flowchart illustrates the experimental procedure used to prepare and analyze fermented and unfermented corncob samples.

2.4 Proximate analysis:

Proximate analysis is a standard method used to determine the basic nutritional composition of feed and food samples. It includes the measurement of moisture, crude protein, crude fat, crude fiber, ash, and essential minerals such as phosphorus and calcium. Several official methods established by the Association of Official Analytical Chemists (AOAC) were used to perform these measurements. The feed analyses were carried out at the Regional Animal Disease Diagnostic Laboratory (RADDL) Region I, located in Sta. Barbara, Pangasinan. Proximate analyses were conducted on oven-dried samples of both unfermented and fermented corncob.

Moisture content was determined using (AOAC Official Method 934.01), where the sample is dried in an oven at 105°C until a constant weight is achieved. Crude protein was analyzed using the Kjeldahl method (AOAC Official Method 2001.11). Ash content was analyzed using furnace-ignition method (AOAC Official Method 942.05). Crude fat was assessed using AnkomXT10 Filter Bag Technique (AOCS Official Procedure Am 5-04). Crude fiber was measured using Ankom^{200} Filter Bag Technique (AOCS Approved Procedure Ba 6a-05).

For mineral analysis, phosphorus content was measured using vanadomolybdate method (ISO 6491. 1998). Lastly, calcium content was analyzed using Titrimetry using $KMnO_4$ (AOAC Official Method 927.02).

III. RESULTS AND DISCUSSION

3.1 Proximate Analysis Content of Unfermented and Fermented Corncob:

Table 1 presents the results on the proximate analysis content of unfermented and fermented corncob. Result indicates that the moisture content increased from 7.7% in unfermented corncob to 9.3% after fermentation of corncob. This is likely due to the introduction of water during fermentation because of the dryness of the corncobs. Other studies typically reported that moisture increases of 5-15% during solid state fermentation, depending on water addition. The crude protein content decreased from 3.6% in unfermented corncob to 1.3% in fermented corncob. This reduction contrasts with most fermentation studies that show protein increases due to microbial biomass production. However, similar protein reductions were observed in cassava peel fermentation (Zhang et al., 2024), likely due to proteolytic activity or nitrogen loss ammonia. A study by Kaur et al. (2023) reported that during solid-state fermentation, crude protein content in a cereal-based substrate decreased significantly from 16.7% to 13.1%, while crude fat content also declined from 4.2% to 2.5%. These reductions were attributed to microbial utilization of nutrients during fermentation. The ash content decreased from 2.7% in unfermented corncob to 0.5 % in fermented corncob. Restuti Fitria et al. (2020), investigated ammonization fermentation of corn husk using a commercial starter (M21 Decomposer) and reported that ash content decreased notably during treatment. Specifically, the ash level reduced from that of untreated corn husk to 1.89 % in the fermented product. The crude fat decreased from 0.6% in unfermented corncob to 0.1% in fermented corncob. Similar findings in the study of Zhang et al., (2022) states that solid state fermentation with *Rhizopus oligosporus* decreased crude fat from 18.5% to 2.3% due to fungal lipases breakdown fats, while some fatty acids are incorporated into microbial biomass. A sudden decrease in crude fiber is observed, dropping from 27.0% in unfermented corncob to 9.3% in fermented corncob. This substantial change indicates that fermentation effectively broke down lignocellulosic components, such as cellulose and hemicellulose, into simpler compounds. Lower crude fiber content improves the digestibility of corncob, making it more suitable for broiler diet, as high fiber levels can limit nutrient absorption. This finding highlights the potential of fermentation to transform corncob into a more nutritionally accessible byproduct, enhancing its value in animal nutrition.

TABLE 1
PROXIMATE ANALYSIS CONTENT (%) OF UNFERMENTED AND FERMENTED CORNCOB

Parameter	Unfermented Corncob	Fermented Corncob
Moisture	7.7	9.3
Crude Protein	3.6	1.3
Ash Content	2.7	0.5
Crude Fat	0.6	0.1
Crude Fiber	27.0	9.3

3.2 Calcium (Ca) and Phosphorus (P) Content of Unfermented and Fermented Corncob:

The results from Table 2 shows the calcium and phosphorus content of unfermented and fermented corncob. Results indicate that phosphorus content in unfermented corncob was 0.1% which decreased to below detectable levels <0.05% after fermentation. This reduction suggests that the fermentation process may have broken down phosphorus containing compounds, such as phytates, or led to leaching. In contrast, calcium levels remained low (<0.05%) in both unfermented and fermented corncob, indicating that fermentation did not enhance calcium content. These findings align with existing studies, such as Tsao et al. (2000), who reported that microbial fermentation reduces phosphorus by degrading phytic acid, and Sharma et.al. (2022), who observed similar trends in fermented agro-industrial wastes. Additionally, the persistently low calcium levels are consistent with research by Bumbie, G.Z. (2017), which highlighted corncobs inherently low calcium content due to its fibrous structure. The reduction in phosphorus could be beneficial for animal feed by lowering anti-nutritional factors, but supplemental calcium would be necessary to balance nutritional value. Further research could explore co-fermentation with calcium rich substrates to improve mineral retention. Overall, the study highlights the role of fermentation in modifying phosphorus content, while emphasizing the need for additional strategies to improve calcium levels in corncob-based products.

TABLE 2
CALCIUM AND PHOSPHORUS CONTENT (%) OF UNFERMENTED AND FERMENTED CORNCOB

Parameter	Unfermented Corncob	Fermented Corncob
Phosphorus	0.1	< 0.05
Calcium	< 0.05	< 0.05

IV. CONCLUSION

This study reveals how solid-state fermentation influence the nutritional composition of corncob, a readily available agro-industrial byproduct. Fermentation improved the digestibility of corncob by markedly reducing its crude fiber content, which can enhance its utility in animal nutrition, particularly for monogastric animals such as broilers. The reduction in anti-nutritional factors such as fiber and phytates as indicated by lower phosphorus levels enhances the bioavailability of nutrients in fermented corncob, as a potential feed ingredient. These findings support the inclusion of fermented corncob into livestock diets for sustainable animal production, resource efficiency, and agro-industrial waste reduction.

Despite its benefits, the fermentation process revealed certain limitations. Notably, reductions in crude protein, fat, and ash content suggest nutrient losses under the current fermentation conditions. Additionally, the consistently low calcium levels before and after fermentation, unsuitable as a complete feed on its own. This implies that fermentation method may need to be improved, or extra nutrients may need to be added to make the feed more balanced.

Fermented corncob is considered as a promising alternative feed ingredient, its incorporation into animal diets helps mitigate the rising costs of traditional feedstuffs such as maize and soybean meal and also contributes to sustainable livestock production by promoting the use of agro-industrial by-products. Its improved digestibility and reduced anti-nutritional content make it suitable for inclusion in poultry and possibly swine diets, provided that nutrient balancing is performed.

The outcomes of this study contribute to the growing body of knowledge supporting circular agriculture and sustainable feed development.

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Response of Soil and Foliar Application of Zn on the quality and productivity of Maize *(Zea mays* L.*)*

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Abstract— *The field experiment was carried out during Kharif, 2024 at Instructional FarmB1 Block (Agronomy), Rajasthan College of Agriculture, MPUAT, Udaipur. The experiment laid out under Factorial RBD design with three replications. The two factors were soil and foliar application of zinc sulphate heptahydrate. Soil application of zinc sulphate included 4 levels i.e. control, 6.25 kgha*$^{-1}$*, 12.5 kg ha*$^{-1}$ *and 25 kgha*$^{-1}$ *and 4 levels of foliar application i.e. control ,0.25%* $ZnSO_4.7H_2O$*, 0.50%* $ZnSO_4$*.* $7H_2O$ *and 0.75%* $ZnSO_4.7H_2O$*. The major challenge of was that how supply the balance diet to rural people and mitigate the problem of micronutrient deficiency in soil. Soil and foliar utilization of zinc increased significantly yield and Yield Attributes but the harvest index was found non-significant. The Protein content and chlorophyll content also increased significantly. The highest values were found with soil application of 25 kg* $ZnSO_4.7H_2O$ *and foliar application of 0.75%* $ZnSO_4.7H_2O$ *which was further at par with 12.5 kg* $ZnSO_4.7H_2O$ *and 0.5%* $ZnSO_4.7H_2O$ *respectively. Judicious soil and foliar application of zinc increase the Zinc status in soil as well as in grain of maize.*

Keywords— Maize (Zea mays L.), Soil and foliar application, Yield attributes, Zinc sulphate, Quality parameters.

I. INTRODUCTION

Among cereal crops, maize (*Zea mays* L.) is considered the third most important cultivated grain worldwide owing to its improved adaptability to a wide spectrum of arid and semi-arid conditions (Shahzad *et al.*, 2020). It is a versatile crop that fits well in the existing cropping systems. The huge potential for export has added the demand for maize all over the world. Maize is a miracle crop called as "Queen of Cereals" due to high productiveness, easy to process, low cost than other cereals (Jaliya *et al.*, 2008). Maize grain has raised nutritive worth as it contains about 72% starch, 10% protein, 4.8% oil, 5.8% fiber and 3.0% sugar (Rafiq *et al.*, 2010).

In India, maize is cultivated on roughly 11.2 million hectares, with a record production estimated at 37.25 mt in 2024–25, and an average national yield of about 3.3 t ha^{-1} (Protect Our Livelihood, 2024). The crop serves multiple purposes: approximately 47% is used as poultry feed, 13% for livestock feed, 13% for direct human consumption, and the remaining 27% for industrial processing and exports.

Zinc is considered the most important micronutrient for normal and healthy plant growth (Tahir *et al*., 2018). It is a structural component or cofactor of various enzymes involved in many biochemical processes. In plants, it is involved in photosynthesis, carbohydrate metabolism, protein metabolism, pollen formation, auxin metabolism, maintenance of membrane integrity, and induction of tolerance against various stresses (Alloway, 2008). It is also essential for nitrogen metabolism and important for the stability of cytoplasmic ribosome's, cell division, as co factor to enzymes like dehydrogenase, proteinase and peptidase in the synthesis of tryptophan, a component of some proteins and a compound needed for production of growth hormones (auxin) such as indole acetic acid (Singh and Singh, 1981).

Plant response to Zn deficiency occurs in terms of decrease in membrane integrity, susceptibility to heat stress, decreased synthesis of carbohydrates, cytochromes nucleotide auxin and chlorophyll. Further, Zn-containing enzymes are also inhibited, which include alcohol dehydrogenase, carbonic anhydrase, Cu-Zn-superoxide dismutase, alkaline phosphatase, phospholipase, carboxypeptidase, and RNA polymerase. Depending on the zinc level, zinc deficiency status of plants can be classified as follows: less than 10 mg kg^{-1} definite zinc deficiency, between 10 and 20 mg kg^{-1} likely to be zinc deficient, more than 20 mg kg^{-1} Zn sufficient.

II. MATERIALS AND METHODS

2.1 Field location and materials:

The experiment was laid out during *kharif* season of 2024 at Instructional Farm B1 Block (Agronomy), Rajasthan College of agriculture, Udaipur, which is situated at 24º35' latitude and 73º42' longitude with an average altitude of 582.2 m above mean sea level. The region falls under agro-climatic zone-IVa of Rajasthan *i.e*. Sub-humid Southern Plain and Aravalli hill.

2.2 Experimental detail:

During the *kharif* of 2024, an experiment was conducted using a factorial randomized block design with three replications. In soil application four treatments were applied: S_1 (control) received no zinc, while S_2, S_3 and S_4 received zinc sulphate at rates of 6.25 kgha^{-1}, 12.5 kg ha^{-1} and 25 kgha^{-1}, respectively. The treatments of foliar application included F_1 (control) with no spray, F_2 with 0.25% $ZnSO_4.7H_2O$ solution, F_3 with 0.50% $ZnSO_4$. $7H_2O$and F_4 with 0.75% $ZnSO_4.7H_2O$concentration. Add lime @ half dose of $ZnSO_4.7H_2O$ as per treatment to avoid scotching effect. The recommended dose of nitrogen (120 kg/ha) was applied in three equal splits, the 1/3 dose as basal and the remaining 1/3 at knee stature stage and remaining 1/3 at 50 % tasseling stage as top dressing at the time of first irrigation through urea. The whole quantity of phosphorus (60 kg/ha) through SSP and potassium (30 kg/ha) through murate of potash was drilled as basal dose at 8-10 cm depth along with 1/3 dose of nitrogen before sowing. Zinc sulphate in the form of $ZnSO_4·7H_2O$ was broadcast uniformly over the designated plots in soil application and foliar application was done at a critical crop growth stage (30, 45 and 60 DAS) using a using a knapsack sprayer to ensure uniform coverage of the foliage.

2.3 Determination methods

From the field, matured cobs from five tagged plants from each plot were plucked and counted. The average cobs plant^{-1} was worked out. These cobs were further taken to observe Length of cob, Number of grains cob^{-1}. The test weight was calculated for the 1000 seeds and measured in grams. Grain yield obtained from each net plot including the tagged plants was sun dried and recorded treatment wise and expressed as kg ha^{-1}. Stover yield was calculated by subtracting seed yield from respective biological yield of each plot and expressed as kg ha^{-1}. The un-threshed produce from net plot area including tagged plants after thorough sun drying was weighed for recording the biological yield and expressed as kg ha^{-1}. The ratio of economic yield (grain yield) to the biological yield was worked out and expressed in percentage as advocated by Donald and Hamblin (1976).

$$HI (\%) = [(\text{Economical yield})/ (\text{biological yield})]*100 \quad (1)$$

Where,

Economical yield = Grain yield,

Biological yield = Grain yield + Stover yield

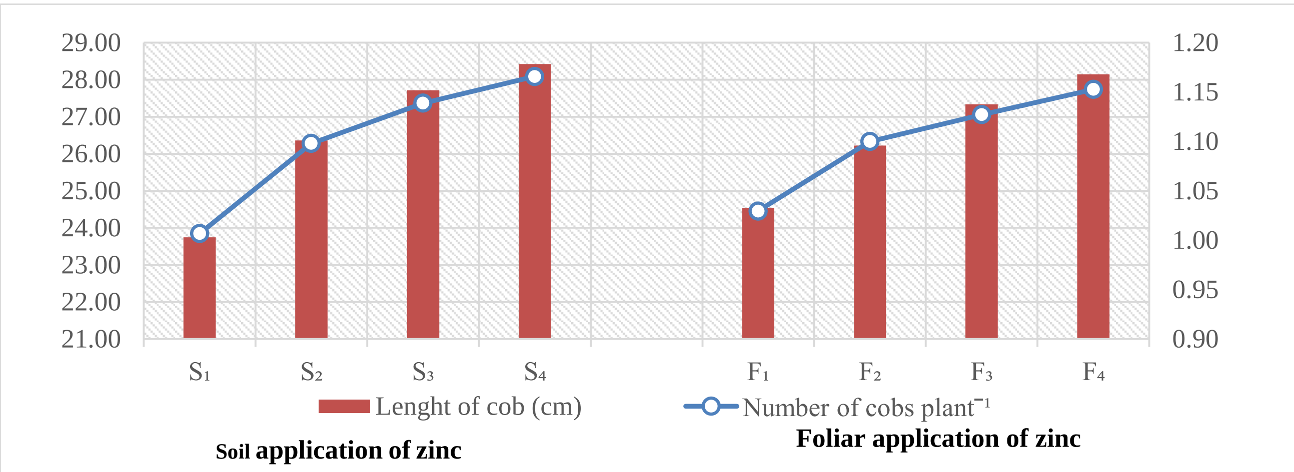
The crude protein content in grain was calculated by multiplying the nitrogen percentage in seed with a factor 6.25 as suggested by A.O.A.C. (1960). The result was expressed as per cent protein content on dry weight basis. The nitrogen content was determined by wet digestion of plant sample with H_2SO_4 and H_2O_2 estimated on colorimeter after development of color with Nessler's reagent (Snell and Snell, 1949). Chlorophyll content in leaves can be measured easily using a SPAD meter. Simply place a healthy, fully expanded leaf (avoiding the midrib) between the sensor clamps and press the button to get a SPAD reading. Take 3–5 readings per leaf and average them for accuracy. Higher SPAD values indicate more chlorophyll and usually better nitrogen status in the plant.

III. RESULTS AND DISCUSSION

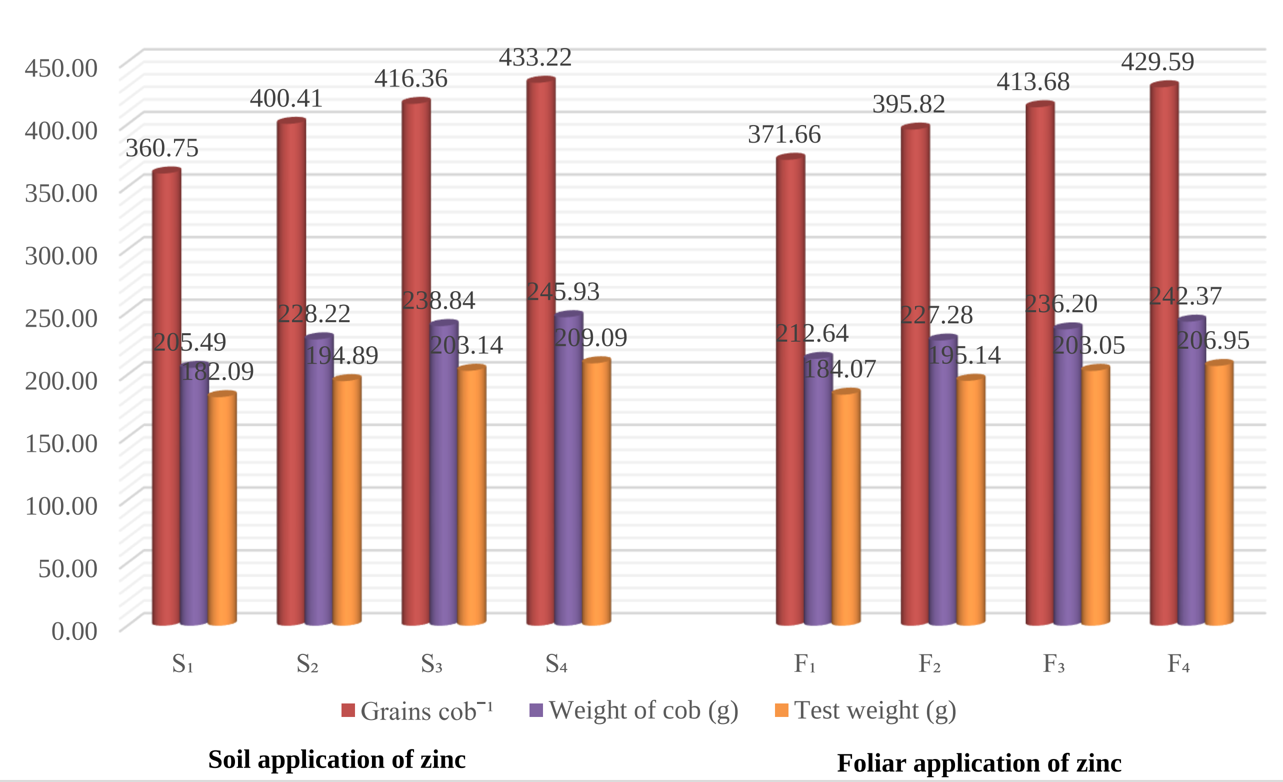
The findings of the present study shown in Table 1 clearly indicate that soil and foliar application of zinc, particularly at the rate of 25 kg $ZnSO_4.7H_2O$ ha^{-1} and 0.75 % $ZnSO_4$ significantly enhances the yield attributes of maize. These attributes include the number of cobs plant^{-1}, cob length, cob weight, number of grains cob^{-1} and test weight. The positive impact of zinc at this dosage can be attributed to its critical physiological and biochemical roles in plant systems. The maize crop fertilized with 25 kg $ZnSO_4.7H_2O$ ha^{-1} produced highest yield attributes *viz*., number of cobs plant^{-1}, length of cob, grains cob^{-1}, weight of cob and test weight of maize which was significantly higher over soil application of 6.25 kg $ZnSO_4.7H_2O$ ha^{-1} and control but remained at par with the soil application of 12.5 kg $ZnSO_4.7H_2O$ ha^{-1}.The superior performance at 25 kg $ZnSO_4.7H_2O$ ha^{-1} compared to the 6.25 kg ha^{-1} and control treatments suggests that zinc deficiency likely constrained growth and yield parameters in the lower-dosage and untreated plots. This is consistent with the findings of Prasad *et al*. (2014), who noted that soil-applied zinc significantly improved the cob length and grain weight in maize, mainly due to its effect on grain filling and nutrient translocation. In terms of foliar spray, the yield attributes *viz*., number of cobs plant^{-1}, length of cob, weight of cob, number of grains cob^{-1} and test weight of maize was significantly increased with foliar application of 0.75% $ZnSO_4.7H_2O$ over foliar application of 0.25% $ZnSO_4.7H_2O$ and control. The increased availability of zinc through foliar application likely improved photosynthetic efficiency and nutrient assimilation, leading to better cob development and grain quality.

TABLE 1
EFFECT OF SOIL AND FOLIAR APPLICATION OF ZINC ON YIELD ATTRIBUTES OF MAIZE

Treatment	Yield attributes				
	No. of cobs plant^{-1}	Length of cob (cm)	Grains cob^{-1} (g)	Weight of cob (g)	Test weight (g)
Soil application					
Control	1.01	23.74	360.75	205.49	182.09
6.25 kg $ZnSO_4$. $7H_2O$ ha^{-1}	1.10	26.36	400.41	228.22	194.89
12.5 kg $ZnSO_4$. $7H_2O$ ha^{-1}	1.14	27.71	416.36	238.84	203.14
25 kg $ZnSO_4$. $7H_2O$ ha^{-1}	1.17	28.42	433.22	245.93	209.09
SEm±	0.02	0.52	7.71	4.54	3.52
C.D. at 0.05	0.05	1.50	22.26	13.10	10.18
Foliar application					
Control	1.03	24.54	371.66	212.64	184.07
0.25% foliar spray of $ZnSO_4$. $7H_2O$	1.10	26.22	395.82	227.28	195.14
0.50% foliar spray of $ZnSO_4$. $7H_2O$	1.13	27.33	413.68	236.20	203.05
0.75% foliar spray of $ZnSO_4$. $7H_2O$	1.15	28.15	429.59	242.37	206.95
SEm±	0.02	0.52	7.71	4.54	3.52
C.D. at 0.05	0.05	1.50	22.26	13.10	10.18



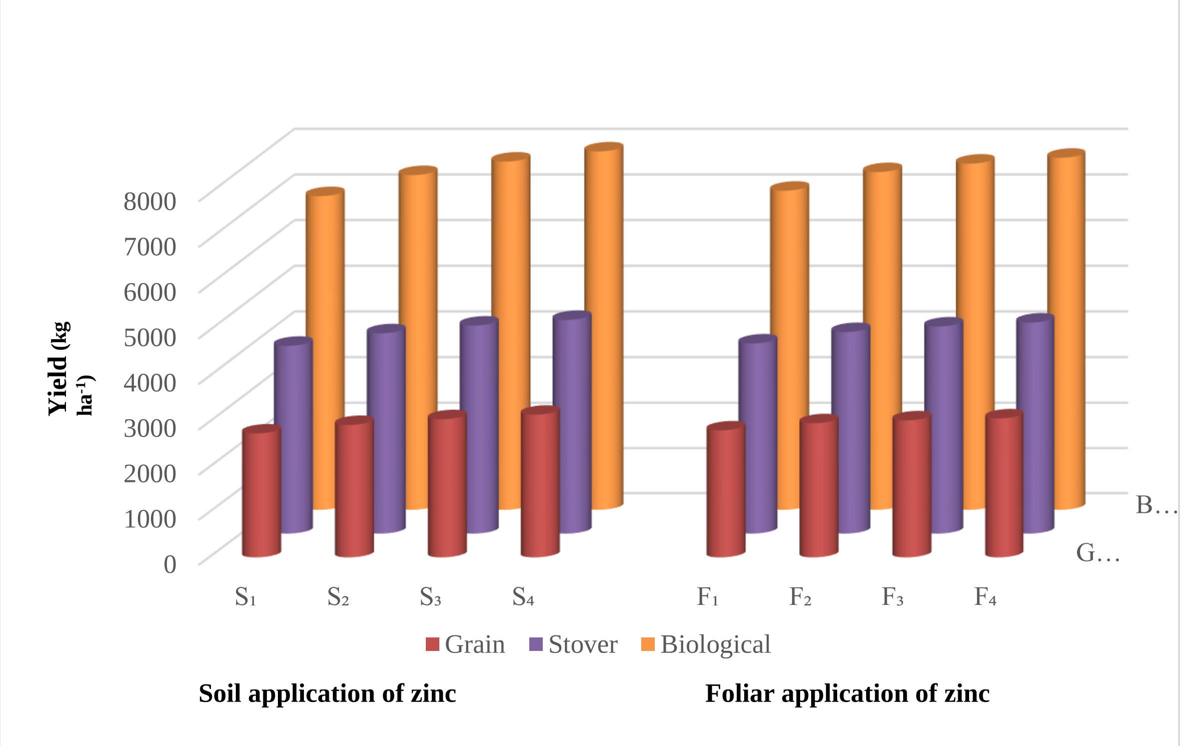
GRAPH 1 (A): Effect of foliar and soil application of zinc on length of cob and number of cobs plant^{-1} of maize



GRAPH 1 (B): Effect of foliar and soil application of zinc on grains cob^{-1}, weight of cob and test weight of maize

TABLE 2
EFFECT OF SOIL AND FOLIAR APPLICATION OF ZINC ON YIELD OF MAIZE

Treatment	Yield (kg ha^{-1})			Harvest index (%)
	Grain	Stover	Biological	
Soil application				
Control	2749	4143	6892	39.90
6.25 kg $ZnSO_4$. $7H_2O$ ha^{-1}	2937	4417	7354	39.93
12.5 kg $ZnSO_4$. $7H_2O$ ha^{-1}	3063	4586	7649	40.07
25 kg $ZnSO_4$. $7H_2O$ ha^{-1}	3162	4710	7872	40.17
SEm±	53	75	107	0.47
C.D. at 0.05	153	218	309	NS
Foliar application				
Control	2817	4194	7011	40.18
0.25% foliar spray of $ZnSO_4$. $7H_2O$	2975	4444	7418	40.11
0.50% foliar spray of $ZnSO_4$. $7H_2O$	3038	4566	7605	39.95
0.75% foliar spray of $ZnSO_4$. $7H_2O$	3081	4652	7733	39.82
SEm±	53	75	107	0.47
C.D. at 0.05	153	218	309	NS



GRAPH 2: Effect of foliar and soil application of zinc on yield of maize

The table 2 shows that maximum grain, Stover and biological yield was recorded under soil application of 25 kg $ZnSO_4.7H_2O$ ha^{-1} which was significantly higher over soil application of 6.25 kg $ZnSO_4.7H_2O$ ha^{-1} and control but remained at par with the soil application of 12.5 kg $ZnSO_4.7H_2O$ ha^{-1}. The significant increase in grain, Stover and biological yield with the soil application of 25 kg $ZnSO_4.7H_2O$ ha^{-1} was to the extent of 7.65, 6.65, 7.05 and 15.00, 13.69, 14.21 per cent over soil application of 6.25 kg $ZnSO_4.7H_2O$ ha^{-1} and control, respectively. The foliar application of 0.25, 0.50 and 0.75% $ZnSO_4.7H_2O$ significantly increased grain and Stover yield over control by 5.59, 7.86, 9.37 and 5.96, 8.88, 10.92 per cent, respectively. The foliar application of 0.75% $ZnSO_4.7H_2O$ significantly increased biological yield by 4.24 and 10.29 over foliar application of 0.50 and 0.25% $ZnSO_4.7H_2O$ and control, respectively but remained at par with foliar application of 0.50% $ZnSO_4.7H_2O$ during experimentation. Different levels of foliar application of zinc could not bring significant improvement in harvest index of maize over control. This increase is attributed to zinc pivotal role in various physiological and biochemical processes within the plant system. Recent studies corroborate these findings. For instance, Ariraman *et al.* (2022) observed that soil application of zinc at 20–25 kg ha^{-1} significantly improved maize grain yield, Stover yield and overall biomass, highlighting zinc's role in enhancing nutrient uptake and utilization efficiency.

The data on chlorophyll content at 50 DAS and protein content in grain of maize as by soil and foliar application of zinc to maize crop are presented in Table 3. The study reveals that the soil application of zinc at 25 kg $ZnSO_4.7H_2O$ ha^{-1} significantly increased chlorophyll content at 50 DAS and protein content in maize grains. These enhancements can be attributed to zinc's critical involvement in photosynthesis, enzyme activation, and protein synthesis. The maize crop fertilized with 25 kg $ZnSO_4.7H_2O$ ha^{-1} recorded highest chlorophyll content in maize at 50 DAS which was significantly higher over soil application of 6.25 kg $ZnSO_4.7H_2O$ ha^{-1} and control but remained at par with the soil application of 12.5 kg $ZnSO_4.7H_2O$ ha^{-1}. Foliar spray of 0.75% $ZnSO_4.7H_2O$ significantly increased chlorophyll content in maize recorded at 50 DAS over foliar spray of 0.50, 0.25% $ZnSO_4.7H_2O$ and control. Zinc is known to influence chlorophyll biosynthesis by enhancing the activity of carbonic anhydrase and other enzymes critical for photosynthetic function. Increased chlorophyll content directly contributes to higher photosynthetic rates, better assimilate production, and ultimately improved crop performance (Liu *et al.,* 2021). Soil application of 25 kg $ZnSO_4.7H_2O$ ha^{-1} significantly improved protein content in grain by 3.60 and 11.57 per cent over soil application of 6.25 kg $ZnSO_4.7H_2O$ ha^{-1} and control, respectively but remained at par with the soil application of soil application of 12.5 kg $ZnSO_4.7H_2O$ ha^{-1}. The protein content in grain was significantly increased with foliar application of 0.75% $ZnSO_4.7H_2O$ over foliar application of 0.25% $ZnSO_4.7H_2O$ and control by 4.77 and 8.95 per cent, respectively. Zinc contributes to protein synthesis by stabilizing ribosomal structure and facilitating enzymatic activity involved in nitrogen metabolism. Foliar zinc enhances N assimilation efficiency, which directly boosts grain protein content (Luo *et al.,* 2021).

TABLE 3
EFFECT OF SOIL AND FOLIAR APPLICATION OF ZINC ON QUALITY PARAMETERS OF MAIZE.

Treatment	Quality parameters		
	Nitrogen content in Grain (%)	Chlorophyll content (SPDA value)	Protein content (%)
Soil application			
Control	1.45	45.57	9.04
6.25 kg $ZnSO_4$. $7H_2O$ ha^{-1}	1.56	47.89	9.73
12.5 kg $ZnSO_4$. $7H_2O$ ha^{-1}	1.59	49.18	9.94
25 kg $ZnSO_4$. $7H_2O$ ha^{-1}	1.61	49.71	10.08
SEm±	0.02	0.54	0.11
C.D. at 0.05	0.05	1.56	0.32
Foliar application			
Control	1.48	43.72	9.24
0.25% foliar spray of $ZnSO_4$. $7H_2O$	1.54	46.72	9.61
0.50% foliar spray of $ZnSO_4$. $7H_2O$	1.58	49.57	9.87
0.75% foliar spray of $ZnSO_4$. $7H_2O$	1.61	52.34	10.07
SEm±	0.02	0.54	0.11
C.D. at 0.05	0.05	1.56	0.32

IV. CONCLUSION

The result concluded that soil and foliar application of zinc sulphate heptahydrate significantly increase yield attributes which include the number of cobs $plant^{-1}$, cob length, cob weight, number of grains cob^{-1} and test weight. The highest values were recorded in 25 kg $ZnSO_4$. $7H_2O$ ha^{-1} and 0.75% foliar spray of $ZnSO_4$. $7H_2O$. The maximum grain, Stover and biological yield was recorded under soil and foliar application of 25 kg $ZnSO_4.7H_2O$ ha^{-1} and 0.75% $ZnSO_4$ which was significantly higher over soil application of 6.25 kg $ZnSO_4.7H_2O$ ha^{-1} and 0.25% $ZnSO_4.7H_2O$ ha^{-1} but remain at par with 12.5 kg $ZnSO_4.7H_2O$ ha^{-1} and 0.50% $ZnSO_4$. . The harvest index increased non significantly in soil and foliar application. The quality parameters increased significantly from control to 25 kg $ZnSO_4.7H_2O$ ha^{-1} in soil application and control to .75% $ZnSO_4$. $7H_2O$ in foliar application

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