ISSN: 2456-1878

International Journal of Environment Agriculture and Biotechnology

(IJEAB)

An open access Peer-Reviewed InternationalJournal

DOI: 10.22161/ijeab.103

Vol.- 10 | Issue - 3 | May-Jun 2025

editor.ijeab@gmail.com | editor@ijeab.com | https://www.ijeab.com/

International Journal of Environment, Agriculture and Biotechnology

(ISSN: 2456-1878)

DOI: 10.22161/ijeab

Vol-10, Issue-3

May - June, 2025

Editor in Chief

Dr. Pietro Paolo Falciglia

Publisher

Infogain Publication

Email: editor.ijeab@gmail.com ; editor@ijeab.com

Web: www.ijeab.com

FOREWORD

I am honoured to introduce this latest issue to the International Journal of Environment, Agriculture and Biotechnology (IJEAB). Our journal is dedicated to disseminating high-quality research and innovative findings that contribute to advancing knowledge in these critical fields.

In this issue, we present a collection of papers that exemplify the diversity and depth of contemporary environmental, agriculture, and biotechnology research. The articles include various topics, from sustainable agricultural practices and environmental conservation strategies to cutting-edge biotechnological innovations. Each contribution has undergone a rigorous peer-review process, ensuring the publication of only the most significant and original research.

Our commitment at IJEAB is to provide a robust platform for researchers, academicians, and practitioners to share their work and engage with a global audience. By fostering an interdisciplinary approach, we aim to bridge the gaps between different areas of study and promote holistic understanding and solutions to the challenges we face in these domains.

We are grateful to our dedicated authors, whose hard work and intellectual rigour are the backbone of our journal. We also extend our appreciation to our reviewers and editorial board members, whose expertise and diligence ensure the high standards of our publication. Finally, we thank our readers for their continued support and engagement.

We hope you find the articles insightful and inspiring as you explore this issue. We encourage you to contribute your research to future issues and join us in our mission to advance knowledge and drive positive change in the environment, agriculture, and biotechnology fields.

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International Journal of Environment, Agriculture and Biotechnology
Vol-10, Issue-3; May-Jun, 2025
Peer-Reviewed International Journal
Journal Home Page Available: https://ijeab.com/
Journal DOI: 10.22161/ijeab

Development of Integrated farming system model: A Case study of a farmer of Jhajjar District of Haryana

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Received: 28 Mar 2025; Received in revised form: 25 Apr 2025; Accepted: 02 May 2025; Available online: 06 May 2025

Abstract— *In India, increasing population coupled with decreasing land holding which results in declining productivity challenged the livelihood of small and marginal farmers. The concept of integrated farming system which integrated various agricultural components and enterprises at farm level helps to have sustainable agriculture production system. Considering the efficacy of integrated farming system, present study was carried out at a farm comprising of bee keeping + horticultural crops + cereal crops,regarding farm income in Malikpur village of district Jhajjar, Haryana during 2021-22. Due to adoption of system net income has increased by 116 percent, indicating that integrated farming system could address the issues of productivity, sustainability and income generation effectively.*

Keywords— ***Integrated Farming System, Productivity, Profitability, Sustainability***

I. INTRODUCTION

Agriculture plays a pivotal role in the Indian economy, contributing to 18.6% of India's Gross Value Added (GVA) and employing 54.6% of the total workforce in agricultural and allied activities. However, Indian agriculture is under significant strain, primarily due to the diminishing trend in average land holdings per individual. The mounting population pressure has resulted in smaller land holdings, with approximately 80% of farming households categorized as small and marginal farmers. This situation intensifies the challenges associated with ensuring food security and livelihoods for these vulnerable groups. Approximately 75% of farmers are affiliated with rural communities in developing economies, where their livelihoods are intricately tied to agriculture and related activities. This reliance on agriculture underscores the significance of Integrated Farming Systems (IFS) for the economic well-being and sustenance of small and marginal farmers (Behera *et al.,* 2018) underscore the pivotal role played by IFS in elevating the economic status and livelihoods of these farmers. It is crucial to acknowledge that a single agricultural endeavor is unlikely to provide sustained income and consistent employment throughout the year for small and marginal farmers, necessitating their adoption of integrated farming systems to achieve these objectives (Nath *et. at.*, 2020).

Integrated farming system involves integrating multiple agricultural components such as crops, livestock, poultry, fishery, bee keeping and agroforestry in a synergistic manner.Among all these components, bee-keeping plays a vital role in agricultural diversification as it offers income and employment opportunities. With the aim of fostering sustainable beekeeping practices in India, the Indian government earmarked a budget of 500 crore rupees for the National Beekeeping and Honey Mission (NBHM) spanning from the fiscal year 2020-21 to 2022-23. Additionally, the government has laid out plans to orchestrate a sequence of nationwide initiatives to promote the concept of a "sweet revolution." This initiative stems from the recognition of beekeeping as an essential component of an integrated farming system (Horo and Singh, 2023).

It was observed that the beekeeping and crops were co-dependent on each other as the cultivated crops were

helping the bees in collecting nectar and bees were augmenting the productivity through pollination of to field and horticultural crops thereby enhancing farm profitability (Chauhan *et al.*, 2017). Considering the above facts, a case study which pertains to Mr. Vinay, farmers of district Jhajjar of state Haryana who has adopted the technique of Integrated farming system (IFS) comprising of bee keeping + horticultural crops + cereal crops was undertaken.

II. MATERIALS AND METHODS

Jhajjar is a district of Haryana state spreading over an area of around 1834 sq km with population density of 523/sq km. Mr. Vinay who is a farmer by profession is also a resident of village Malikpur, Jhajjar, Haryana. The total cultivable land available with him is around 3 acre. After completing his B.Tech education he joined his father's business which was started with 27 boxes. Initially, he cultured bee on his farm only and the productivity was very low as compared to the standards. After sometime, he came in contact and participated in various activities of Krishi Vigyan Kendra, Jhajjar. He worked hard to serve people with best quality of honey.

IFS model comprising of honey bee, fish farming, goat rearing, horticultural crops, cereals crop and many more components was demonstrated as KVK Farm, Jhajjar. He adopted the IFS technology and this case study was carried out to evaluate the farm income of Mr. Vinay.

III. RESULT AND DISCUSSION

Beekeeping is compatible with a variety of multi-crop-based cropping systems that ensure the continuous availability of nectar and pollen resources essential for the well-being of bee colonies. Presently Mr. Vinay owned 1200 colonies of honeybees besides this he also owned honey processing plant in his village and gets an annual net income of Rs. 11,11,050. The net income increased by 116 percent by adopting improved agricultural practices and integrated farming system. The implementation of an Integrated Farming System (IFS) offers a sustainable avenue for year-round gainful employment and the assurance of a higher income, consequently leading to an improved standard of living. Detailed information regarding the income generated from various components is provided in Table 1. Integrated farming system increased the farm income by following ways:

1. Diversification: It minimizes the production constraints which are responsible for yield gaps. Diversification can increase income through adoption of farming system approaches.
2. Productivity: Integration of enterprises leads to increased productivity per unit area, reduced risk and finally sustainability.
3. Employment generation: By adopting bee-keeping in IFS model we not only improve the social-economic condition as well as we can generate the employment and other career opportunities for the youth.
4. Profitability and sustainability: The system provides the opportunity to increase the profit and their social-earning which contributes towards sustainable development.
5. Nutritional security: Various components of integrated farming system enable the nutritional security by increasing the productivity of crops from the same piece of land.

Table1: Income from different component

Sr. No.	Component	Enterprise	Area (in acre)	B:C ratio	Gross Income	Net income
1	Bee keeping	Honey and its by-products	1200 colonies	3.69	1350000	985000
2	Field Crops	Paddy+ Wheat	2 acre	2.25	135550	75550
3	Horticultural Crops	Guava Orchard+ Snap melon + Cauliflower	1 acre	2.19	92700	50500

Current scenario

Beekeeping is a profitable venture under IFS and it could result in added returns through production of honey and its by-product as well as increasing the productivity of field and horticultural crops. Mr. Vinay currently sustains his livelihood through an integrated farming system encompassing various varieties of high-quality honey, such as ajwain honey, mustard honey, jamun honey, eucalyptus honey, kikar honey, neem honey, and numerous others.Along with honey production he also supply pollens, honey gel and wax. He is owner of his own brand named Bee Hut. Many a time KVK, Jhajjar has motivated and

helped him to participate in different district and state level exhibitions for development of his skills and promoting his produce. He was awarded and felicitated many time,

Shahad Ratan Award at 3rd Agri Leadership summit, 2018 by Chief Minister of Haryana

Felicitation conferred by KVK, Jhajjar

Progressive Farmer Award, Haryana Krishi Vikas Mela, 2023 by Chief Minister of Haryana

Success of Mr. Vinay affects the nearby farmers effectively and motivates others to adapt the integrated farming system.

IV. CONCLUSION

Never the less, agriculture remains of utmost priority for economic reasons, as it still accounts for a substantial part of GDP and employment. Despite major contribution of agriculture in Indian GDP, the income of majority of farmers did not grow much and remained low in rural areas. For such farmers integrated farming system will prove a milestone as it is low cost technology and allows farmer to undertake the double benefit from the same area of work. IFS not only encourages ecological awareness but also helps in the promotion of rural and small scale industry which would eventually help in increasing the income of farmers by supplementing in agriculture.

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International Journal of Environment, Agriculture and Biotechnology
Vol-10, Issue-3; May-Jun, 2025
Peer-Reviewed International Journal
Journal Home Page Available: https://ijeab.com/
Journal DOI: 10.22161/ijeab

Analyzing Farmer's Perception of the Soil Health Card Scheme and Its Role in Reducing Farming Production Costs

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Received: 20 Feb 2025; Received in revised form: 22 Apr 2025; Accepted: 27 Apr 2025; Available online: 06 May 2025

Abstract— *Injudicious and haphazard use of chemical fertiliser in agriculture is a matter of concern in recent times. To avoid the deterioration of soil in the long run and to visualise the importance of balanced nutrients in crop production. The Soil Health Card (SHC) provides soil health data to get appropriate guidance to the farmers for the efficient use of fertiliser to cultivate crops based on soil health analysis. The SHC is a simple document which contains useful data on soil based on chemical analysis of the soil to describe soil health in terms of its nutrient availability and its physical and chemical properties. The soil health card is also made available online for farmers. To understand the feelings of the farmers against this system, there is an urgent need to study the degree of positive or negative disposition associated with farmers towards the usefulness and application of the Soil Health Card. Thus, the present study on farmers' perception regarding the soil health card was undertaken. The study was conducted in three blocks of the Rewari district with 120 Soil health cardholders. The findings revealed that the majority of the farmers had knowledge and understanding about the utility of the soil health card. The findings further reveal that a maximum number of Soil health card holders had a favourable attitude towards the Soil health card, followed by less favourable and most favourable attitudes towards the Soil health card. Among constraints, difficulty in calculating fertiliser dose on the basis of nutrient status of soil was the major constraint faced by the majority of the respondents.*

Keywords— ***Perception. Soil health card, Productivity***

I. INTRODUCTION

India is principally an agricultural country but still Indian farmers continue to be the poorest in the world. India has disparate climatic conditions, diversified soils which are rich in fertility and has immense potential to produce discrete agricultural products and become one among the top leading producer countries in agriculture. Though India has abundant natural resources as raw materials, India lags far behind in ensuring food security for its own citizens. This situation is a combined repercussion of various factors, such as lack in use of advanced scientific methods in agriculture, dearth of modern machinery to the farmers, lack of electricity in villages, lack of consciousness among farming community and lack of proper financial support. Majority of farmers are uneducated and they believed that anything for improving soil fertility must have a direct response and the more they add it, the better things should become. So same notion they followed when it comes to the concept of fertilizer utilization. Indeed, presently farmers are unaware of overuse of fertilizer and they keep on adding fertilizers in a view to get good production, but heating and complexation end up burning the roots.

Soil health is not a new concept. Greek and Roman philosophers were aware of the importance of soil health to agricultural prosperity over 2000 years ago, and reflected this awareness in their treatises on farm management. As the science of agriculture developed, plant nutrients were identified as essential components of soil health, at least with respect to sustaining biological productivity. This resulted in a paradigm of plant nutrition

and soil management that relied heavily on the use of artificial fertilizers and intensive tillage. Increasing concern over agriculture's impact on the environment has created renewed interest in soil health. Efforts to define soil health in the context of multiple soil functions began in 1977, and were followed by more formalized definitions, selection of indicators, and specific strategies to enhance soil health. Soil fertility is largely maintained by the application of compost and manure, but in recent years a decline in soil fertility has been reported.

To overcome declining output resulting from decreasing soil fertility and productivity, farmers need to improve their production techniques. The decision to participate in new agricultural technologies depends on farmer's perception which is a key determinant in influencing adoption. Technology adoption is also influenced by perceived profitability, costs of the technology and clarity at which the new knowledge and information is communicated in a recipient population. Farmers' perceptions regarding compatibility of sustainable practices with their farming systems have emerged as the best predictor of adoption of such practices. Since perception refers to an individual's current appraisal of an object or program, assessing farmers' perceptions is an important means to evaluate their knowledge level on a particular issue. People base their perceptions on past experience and knowledge thus; if a person has limited knowledge and experience about a technology then he cannot accurately perceive it or form an opinion on it. Keeping this in mind the present study entitled "Farmers' perception regarding soil health card" was conducted.

District	Block	Villages	No. of respondents
Rewari	**Dharuhera**	Bhatsana	**23**
		Khaliawas	**17**
		Khar Khara	**26**
		Khatawali	**21**
		Masani	**33**

II. RESEARCH METHODOLOGY

The present investigation was carried out in Rewari district of Haryana. From Rewari district five blocks of Dharuhera were selected purposively because of having maximum number of soil health card holders. As per the list provided by soil testing laboratory of Department of Farmers Welfare and Agriculture Development. For selection of respondent systematic random sampling method was used. Form each village, every 2nd soil health card holder was selected as respondents. So, in all 120 soil heath card holders were investigated to collect the data. Thus, selected sample was comprised of 120 soil health card holders.

III. RESULTS AND DISCUSSION

3.1 Profile and Socio-Economic Characteristics of the Farmers: -

In this section, results relating to personal profile of the respondent that is age, education, extension contact, landholding, annual income, farm power, crop sequence , nutrient status have been presented in subsequent table. These variables are explained one by one as follows:

Table 1. profile and Socio-economic characteristics of the farmers(n=120)

Sr. No	Independent variable	Category	Frequency	Percentage
1	**Age group**	Young (21-34 yrs.)	40	33.33
		Middle (34-49 yrs.)	50	41.67
		Old (above 50 yrs.)	30	25.00
2	**Education**	Illiterate	25	20.83
		Primary school	32	26.67
		Inter/Diploma	42	35.00
		Graduation and above	21	17.50
3	**Family type**	Joint	90	75.00
		Nuclear	30	25.00
4	**Extension contacts**	Low (21-29)	40	33.33
		Medium (30-38)	50	41.67
		High (39-47)	30	25.00
5	**Occupation**	Agriculture	80	66.67
		Agriculture + service	21	17.5

		Agriculture + Business	19	15.83
6	**Land holding**	Small (up to 1 ha.)	50	41.67
		Medium (1 to 2 ha.)	42	35.00
		Large (above 2 ha.)	28	23.33
7	**Annual income**	Low (up to 1 Lac)	31	25.83
		Medium (1-1.5 Lac)	54	45.00
		High (above 1.5 Lac)	35	29.17
8	**Farm power**	Low (up to 1)	33	27.5
		Medium (2 to 7)	51	42.5
		High (up to 10)	36	30.00
9	**Crop sequence**	Low (9-13)	55	45.83
		Medium (14-17)	33	27.50
		High (18-21)	32	26.67
10	**Nutrient status**	Low (21-27)	41	34.17
		Medium (28- 33)	48	40.00
		High (34-40)	31	25.83
11	**Scientific orientation**	Low (9-19)	55	45.83
		Medium (20-29)	26	21.67
		High (30-39)	39	32.50

The data (Table 1) indicated that majority of the respondents (41.67 percent) from middle age group followed by 33.33percent and 25 percent from young and old age respectively. In case of education majority (35 percent) of respondents was educated up to high secondary group. Only whereas (26.67 percent) upto primary school only. It was indicated in table 1 that 75 percent of the respondents were living in joint family.

The data in table 1 further indicated that nearly (21.7 percent) respondents fall under medium category regarding Extension contact, while 33.33 percent belongs to low category and 25 percent of respondent falls under high category. This might be due to fact that the farmers are not approaching the extension agencies for solving day to day problems of agriculture and also it reflects extension programmes not related to agriculture.

The data in table 1 also shows that almost (66.67 percent) of the respondents have farming as there main occupation. It also indicates that majority (41.67 percent) of the respondents belongs to small land holding i.e. up to 1 ha., 35 percent medium holding and 23.33 percent possessed large land holding.

It was indicated in table 1 that majority (45 percent) of respondents getting 1 to 1.5 Lac income per annum, 25.83 percent respondent gained up to 1lac income and 29.17 percent of respondents gained above 1.5lac income per year. It was indicated that 32.50 percent of respondents had medium level of farm power.

It was indicated from the table 1 that 45.83 percent of respondents belong to low crop sequence whereas 27.50 percent and 26.67 percent of respondents had medium and high crop sequence respectively.

The data in table 1 depicted that majority (45.83 percent) of the respondents had low scientific orientation, 32.50 percent of the respondents had high scientific orientation and 21.67 percent possessed medium scientific orientation.

3.2 Perception of farmers regarding soil health cards

It was observed (Table 2) that 43.33 percent of respondents had medium level of perception followed by low level of perception(32.50 percent) and high level of perception observed is 24.17 percent. Thus, it could be concluded that majority of the beneficiaries were found to have moderate level of perception regarding various components of Soil health card. These results are in accordance with the findings of **kumari (2016), Bandyopadhyay (2018) and Charle (2018).**

Table 2. Perception level of farmers(n=120)

S. No.	Perception on soil health Card	Frequency	Percentage
1.	**Low (16-20)**	39	32.50
2.	**Medium (21-24)**	52	43.33
3.	**High (25-28)**	29	24.17
Total		**120**	**100.00**

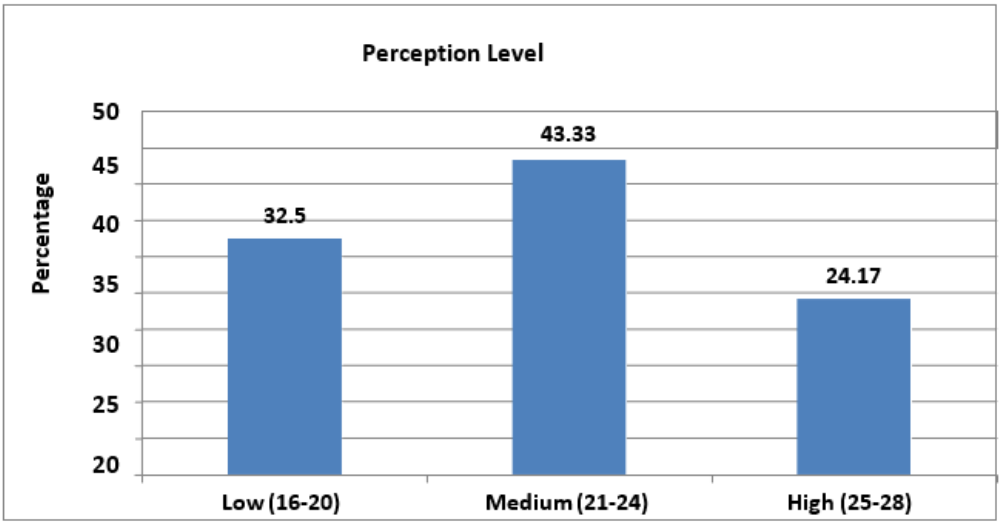

Table 3. Statement analysis of Perception of respondents regarding Soil Health Card (n=120)

S. No.	STATEMENTS	A (3)		UD (2)		DA (1)	
		f	%	f	%	F	%
1	Soil health card can be obtained after the soil testing	112	**93.33**	8	**6.67**	0	**0**
2	Soil health can be maintained by fulfilling the nutrient deficiency in soil as given in soil health card	90	**75**	28	**23.33**	2	**1.67**
3	Soil fertility and productivity can be maintained with the help of soil health card	87	**72.5**	27	**22.5**	6	**5**
4	Systematic crop planning can be done by using soil health card information	72	**60**	38	**31.67**	10	**8.33**
5	Farming can be done in scientific way by using soil health card information	85	**70.83**	32	**26.67**	3	**2.5**
6	Soil health card may help to establish coordination among farmers, extension workers and experts	65	**54.17**	48	**40**	7	**5.83**
7	The quantity of available nutrients in soil can be known with help soil health card	68	**56.67**	50	**41.67**	2	**1.67**
8	Soil health card gives information about number of fertilizers to be applied	88	**73.33**	27	**22.5**	5	**4.17**
9	Unnecessary expenditure can be reduced by using information given in soil health card	85	**70.83**	31	**25.83**	4	**3.33**
10	Acidity, alkalinity of the soils can be known with help of soil health card information	75	**62.5**	43	**35.83**	2	**1.67**
11	We can know the quantity of available organic elements in the soil by information given in soil health card.	62	**51.67**	55	**45.83**	3	**2.5**
12	We can apply the necessary quantity of organic matter in the soil with the help of information given in soil health card	89	**74.17**	27	**22.5**	4	**3.33**
13	Bio fertilizers can be applied with the help of soil health card information	87	**72.5**	21	**17.5**	12	**10**

14	We can apply the necessary quantity of nitrogen into the soil with the help of information given in soil health card	48	**40**	52	**43.33**	20	**16.67**
15	We can apply the necessary quantity of phosphorus into the soil with the help of information given in soil health card.	61	**50.83**	49	**40.83**	10	**8.33**
16	We can apply the necessary quantity of potassium into the soil with the help of information given in soil health card.	80	**66.67**	32	**26.67**	8	**6.67**
17	We can apply the necessary quantity of sulphur into the soil with the help of information given in soil health card.	60	**50**	48	**40**	12	**10**
18	We can apply the necessary quantity of zinc into the soil with the help of information given in soil health card.	61	**50.83**	50	**41.67**	9	**7.5**
19	We can apply the necessary quantity of iron into the soil with the help of information given in soil health card.	69	**57.5**	40	**33.33**	11	**9.17**
20	We can apply the necessary quantity of magnesium in the soil with the help of information given in soil health card.	64	**53.33**	39	**32.5**	17	**14.17**

(A= Agree, UD= Undecided, DA= Disagree)

It is evident in Table 3 that, majority (93.33%) of farmers perceived "agree" towards the statement "Soil health card can be obtained after the soil testing". Among undecided category of perception statement, we can know the quantity of available organic elements in the soil by information given in soil health card was perceived undecided by 45.83 per cent of farmers. Among disagree category of perception statement "We can apply the necessary quantity of nitrogen into the soil with the help of information given in soil health card" was perceived disagree by 16.67 per cent of farmers.

The possible reasons for the above trend of perception may be generally soil health cards can be issued only after testing the soil samples and farmers are well perceived about brief information of soil health cards. Acidity and alkalinity which are the cause for problematic soils require reclamation measures which show the result in long run only without any immediate effect. This long run action of the reclamation measures which is invisible in short run made farmers to disagree with the statement regarding alkalinity and salinity. Though Soil health card helps to increase soil fertility and take corrective measures against problematic soils the result is invisible in short run. Hence, the measures which require long run for visibility are perceived as disagree by the farmers.

Association between selected independent variables with perception level of respondents towards Soil Health Card depicted below:

S. No.	Characteristics	Correlation coefficients ('r' values)
1	Age	**0.997***
2	Education	**0.928***
3	Family Type	**0.255****
4	Extension contacts	**0.991***
5	Occupation	**0.913***
6	Land holding	**0.568****
7	Annual income	**0.818***
8	Farm power	**0.0809NS**
9	Nutrient status	**-0.036**
10	Crop sequence	**0.984***
11	**Scientific orientation**	**-0.513**

***Correlation is significant at the 0.01 level of probability.**

****= Correlation is significant at the 0.05 level of probability NS= non-significant.**

It was observed from the Table 4 that age, education, occupation extension contact, annual income, crop sequence was positively and significantly correlated at 0.01 level of probability and land holding, family type was positively and significantly correlated at 0.05 level of probability with the perception level of farmers towards soil health card scheme. Whereas, farm power is non-significantly correlated with the perception level of farmers towards soil health card scheme.

The variables such as nutrient status, scientific orientation was negatively correlated with the perception level of the farmers towards soil health card scheme.

IV. CONCLUSION

It is concluded that the majority of the respondents using the Soil Health Card Scheme were from the middle age group, had educated up to the middle level of education, had a small category of land holding, had a medium income group, had medium extension contacts, had a medium level of farm power, had a low crop sequence, had a medium

nutrient status, and had a medium scientific orientation. Most of the respondents belonged to joint families and perceived agriculture as their main occupation. Meanwhile, most of them had a medium level of perception regarding soil health. The respondents faced several problems regarding the use of the soil health card. The difficulty in calculating fertilizer dose on the basis of the nutrient status of the soil, followed by the time gap between soil samples taken and issuing SHC, is too high for successive crops.

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International Journal of Environment, Agriculture and Biotechnology
Vol-10, Issue-3; May-Jun, 2025
Peer-Reviewed International Journal
Journal Home Page Available: https://ijeab.com/
Journal DOI: 10.22161/ijeab

Vegan Paneer– A Dairy-Free Alternative

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Received: 27 Mar 2025; Received in revised form: 25 Apr 2025; Accepted: 02 May 2025; Available online: 07 May 2025

Abstract— *As more people look for healthier and eco-friendly food choices, vegan paneer is becoming a popular alternative to traditional dairy paneer. This review takes a closer look at why vegan paneer is gaining traction, touching on its nutritional benefits, market trends, and the growing demand from people with lactose intolerance and dairy allergies. The world market, worth about $9 billion in 2022, is expected to expand significantly, with India's market to reach INR 1848 billion by 2032. The demand for plant-based alternatives is also on the rise, as seen in the $270 million sales of non-dairy cheese in the US in 2020.Vegan paneer comes in various forms, including soy-based, nut-based, and millet-based options, each with unique flavors and textures. While it offers benefits like lower cholesterol and being allergen-free, one of the main challenges is achieving the same taste and texture as dairy paneer. There are also concerns about nutritional gaps, making fortification an essential part of product development. Innovation is key to making plant-based alternatives more appealing and accessible. As the industry evolves, the focus remains on creating delicious, nutritious, and sustainable vegan paneer options that meet consumer expectations and contribute to a better food future.*

Keywords— ***Vegan paneer, dairy alternatives, nutritional benefits, market dynamics, lactose intolerance, plant-based diets, sustainability.***

I. INTRODUCTION

Dairy products are popular for their nutritional value and appealing flavours, offering fat, protein, vitamins, and calcium [1]. However, changing dietary habits, particularly in developed countries, have increased demand for sustainable, plant-based alternatives. This shift is driven by health, ethical reasons, and concerns over dairy's environmental impact, including greenhouse gas emissions contributing to global warming.Rising dairy costs have further spurred research into casein and fat replacements, aiming to create dairy-free products with comparable sensory and functional qualities[2].

Paneer is a highly nutritious and affordable source of animal protein, making it a staple for many vegetarians. This soft, unripened cheese is widely consumed in South Asia and is made by heating the milk and curdling it with an acid. Unlike some other cheeses, paneer is unaged, does not melt, and is non-fermentative. Nutritionally, paneer is rich in fat (around 26%) and protein (around 21%), with a biological protein value between 80 and 86. It also contains a small amount of lactose (around 3%) and ash (about 1.9%) [3]. These properties make it a valuable protein source, particularly for individuals following a vegetarian diet.

Vegan paneer is a dairy-free alternative to traditional paneer, created for people who follow a vegan diet, are lactose-intolerant, or want a more eco-friendly food option. It is made to resemble regular paneer in texture, taste, and nutrition while using plant-based ingredients instead of milk. Unlike dairy paneer, vegan versions are made from ingredients like soy, almonds, cashews, or even newer options like coconut and millet milk. These plant-based choices help achieve the soft, crumbly texture of traditional paneer while offering added health benefits,

such as lower cholesterol and being free from common allergens [4].

Researchers have also explored making a groundnut-based dehydrated version of vegan paneer, designed to be a convenient, high-protein option [5].

1.1 Size of the Traditional Paneer Market Globally and in India

1.1.1 Global market

In 2022, the world paneer market was to be at $9.4 billion, and it is predicted to keep expanding. The growing demand for paneer can be linked to various factors, such as population growth, shifting dietary habits, a rising interest in ethnic cuisines, and its inclusion in western fast-food menus [6].

1.1.2 Indian market

According to the latest reports from the IMARC , the market in India was valued at INR 570.8 billion in 2023 [6]. It is projected to grow significantly, reaching INR 1848.9 billion by 2032, with a compound annual growth rate (CAGR) of 13.95% between 2023 and 2032.Curdled dairy products such as paneer, chenna, and sandesh are highly favoured by the Indian population. Among these, paneer stands out as the most popular, accounting for about 5% of the total milk produced in India [7].

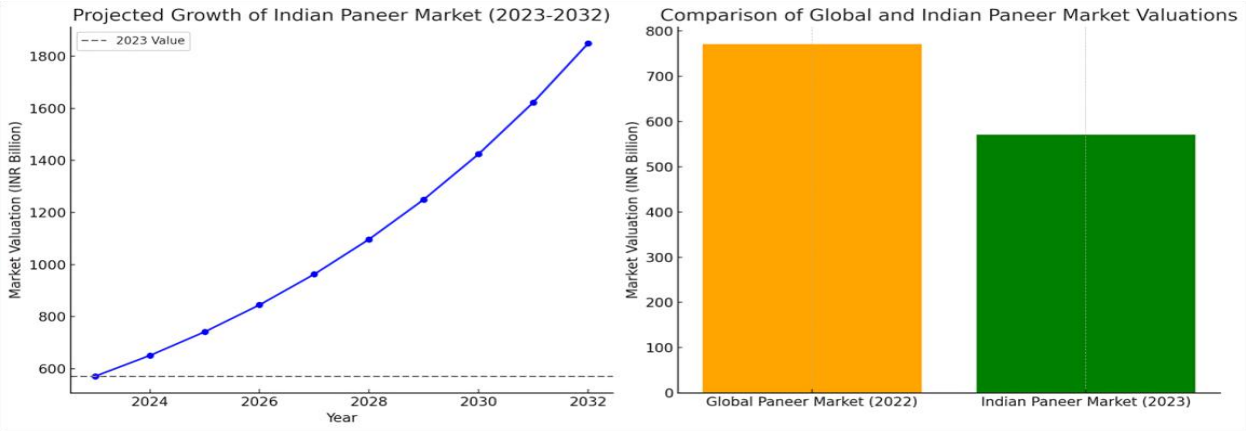

Fig.1: Size of the Traditional Paneer Market Globally and in India

1.2 Size of vegan alternatives market

The demand for cheese alternatives is rising quickly, especially among vegans and people who are lactose intolerant [8]. However, creating a plant-based cheese that matches the taste, texture, and meltability of traditional dairy cheese remains a major challenge. Some industry experts even consider it "almost impossible" [9]. In 2020, sales of non-dairy cheese in the US hit $270 million, a 42.5% jump from 2019 [10]. This rapid growth has made plant-based cheese one of the fastest-expanding area in the plant-based food industry [2]. Looking ahead, the vegan cheese market is expected to grow by nearly 12% between 2021 and 2028 [6].

The dairy substitute market has been one of the fastest-growing industries in recent years. Plant-based beverages are now more popular than dairy milk, largely because they are free from lactose and cholesterol [9]. The increasing demand for plant-based milk alternatives is driven by several factors, including a rise in cow milk allergies, lactose intolerance, high cholesterol levels, and a growing preference for vegetarian and plant-based diets. As a result, a variety of veganbased milks, such as soy milk, almond milk, and oat milkhave entered the market as dairy substitutes. These alternatives are becoming more widely accepted, with plant-based milk sales increasing by 20% in 2020. That year, dairy milk's annual revenue growth was half that of plant-based milk. By 2020, plant-based milk held a 15% share of the retail market in most households, and experts predict that nearly 40% of homes will adopt these products in the future [8].

1.3 Consumer preferences of Dairy paneer in India

A survey of 500 people in India on dairy paneer consumption found that 32% eat paneer two to three times a month, while only 4% consume it daily, suggesting that paneer is not a staple for most households. Additionally, one in four respondents buy paneer regularly, indicating that purchases are generally infrequent. Many consumers are skeptical about the quality, freshness, and taste of branded paneer, often preferring local vendors who are believed to offer fresher options. Interestingly, 17% of respondents have never tried branded paneer, pointing to a lack of trial purchases and emphasizing the need for better marketing strategies [11].

This article provides an in-depth look at the rising demand for vegan paneer as a healthy and eco-friendly alternative to traditional dairy paneer. It explores the nutritional

benefits of paneer, market trends for both dairy and plant-based options, and the growing shift toward plant-based diets. The discussion covers both the advantages and challenges of vegan paneer, including its suitability for people with lactose intolerance or dairy allergies, while also addressing concerns about nutritional deficiencies and the need for fortification. It also examines different types of vegan paneer, such as soy-based, nut-based, and millet-based varieties, focusing on their texture, taste, and functional properties. Ultimately, the article highlights the need for continuous innovation in developing plant-based paneer options that meet consumer expectations and support a more sustainable food system.

II. NEED FOR VEGAN PANEER

2.1 Lactose Intolerance and Milk Allergies

Allergies to cow's milk, eggs, wheat, and soy often fade during childhood, whereas allergies to tree nuts, peanuts, and seafood are more likely to last a lifetime [12]. Since cow's milk is introduced early in life, it is one of the first foods that can cause allergic reactions. The two most common issues linked to cow's milk consumption arecow's milk allergyand lactose intolerance[8].

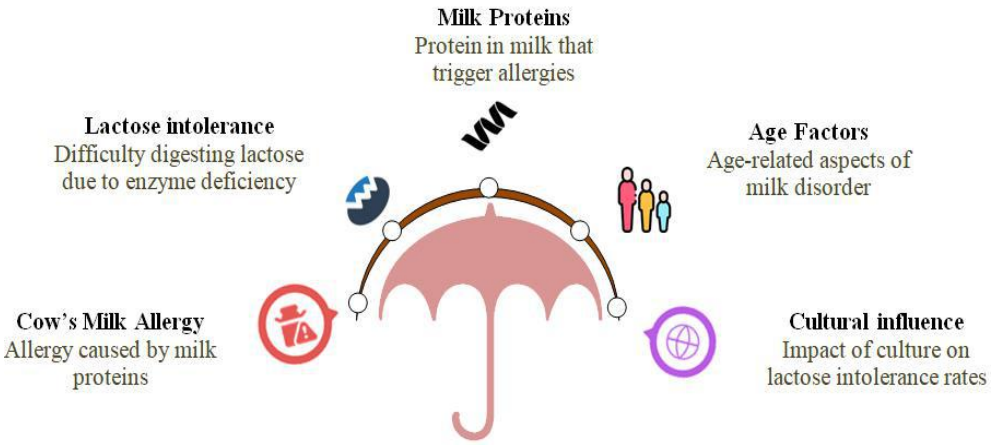

Fig.2: Understanding of lactose intolerance and dairy allergies

Allergies occur when the immune system mistakenly sees a harmless food antigen as a threat, triggering a defensive reaction after consumption. In case of cow's milk allergy. The body's immune system identifies and reacts to certain milk proteins, such as casein, β-lactoglobulin, α-lactalbumin, serum albumin, and immunoglobulins [13]. Lactose intolerance, on the other hand, is a digestive condition that affects people of all ages. It happens when the body lacks enough lactase, the enzyme needed to break down lactose—the main carbohydrate in milk. This leads to symptoms associated with lactose maldigestion, as lactose makes up 2% to 8% of the solid portion of milk [14]. Lactose is a disaccharide made of glucose and galactose, serving as an energy source. While mammals, including humans, are born with the ability to digest lactose, about 75% of the global population develops lactose intolerance, with adult prevalence remaining under 20% [15]. Populations with a history of dairy consumption tend to have lower rates of lactose intolerance than those relying more on agriculture [16]. Infants and older adults are more prone to lactose intolerance, although newborns usually produce enough lactase [17]. Temporary intolerance can occur in children after intestinal infections or food allergies, as these conditions reduce lactase production. Recovery may take weeks or months, during which lactose-containing foods may be poorly tolerated. A natural decline in lactase production starts around ages 3 to 6, and in some cases, it ceases entirely. Symptoms of lactose intolerance typically appear during adolescence or early adulthood [17].

2.2 Health Trends

People who follow vegetarian diets tend to be more health-conscious, have a leaner body composition, and often enjoy better overall health compared to those who eat both plant and animal foods. However, these differences may also mean that vegetarians naturally have fewer risk factors for certain health conditions, which could affect how research findings apply to the general population. This might lead to an overestimation of the health benefits of vegetarian diets. Within plant-based diets, the vegan lifestyle—eliminating all animal-derived products—has become increasingly popular. While some studies suggest that a vegan diet offers health benefits, the evidence is still not entirely conclusive [18].

2.3 Adulteration of traditional paneer

The issue of adulterated paneer, especially those made with unsaturated vegetable fats, is becoming a major food safety and public health concern. To cut costs and extend shelf life, some manufacturers use cheaper and potentially harmful substitutes like unsaturated vegetable fats or synthetic oils [19]. While these additives help keep paneer soft and fresh for longer, they pose serious health risks.The dangers of consuming adulterated paneer go beyond immediate digestive problems like nausea, vomiting, and diarrhea[20]. Over time, these harmful ingredients can contribute to severe health issues such as liver and kidney damage, heart disease, weakened immunity, and even developmental delays in children. Raising consumer awareness and implementing stricter regulations are essential to ensuring the safety and quality of paneer available in the market [21].

2.4 Sustainability

Plant-based diets offer substantial environmental benefits, such as decreased resource utilization, minimized greenhouse gas emissions, and enhanced biodiversity compared to animal-based diets [22]. Shifting toward predominantly plant-based eating habits could play a crucial role in addressing climate change and ensuring global food security for a growing population. However, there are still challenges to overcome. These include the environmental impact of large-scale monoculture farming, emissions from transporting plant-based products, and socioeconomic factors like affordability and accessibility [23]. Addressing these issues is essential to making plant-based diets a truly sustainable and viable solution for the future.

III. DIFFERENT TYPES OF VEGAN PANEER PRODUCTS

3.1 Soy-based paneer

Tofu, commonly known as soy-based paneer, has been extensively studied for its nutritional advantages and potential as a dairy-free alternative. Researchers have explored the use of soy protein isolate (SPI) to enhance the nutritional profile of paneer while reducing fat content. Findings suggest that adding SPI boosts yield, protein, ash, and moisture levels while lowering fat and calorie intake. However, exceeding 0.2% SPI led to an undesirable beany taste, which negatively impacted its overall acceptability [24].

Another study focused on producing soy paneer by combining soymilk and buffalo milk in a 70:30 ratio, using 2% acetic acid for coagulation. The results indicated that this blend improved the texture and nutritional value of soy paneer, making it a more affordable and healthy option [25].

Further research examined different proportions of toned milk and soymilk (80:20, 70:30, 60:40) to determine the ideal combination for enhancing both taste and nutrition. The study revealed that certain blends significantly improved the sensory appeal and health benefits of soy paneer, positioning it as a plant-based alternative to milk paneer [26].

3.2 Nut-Based Paneer

Nut-based substitutes for traditional dairy paneer have been extensively researched developed a quick-to-prepare paneer alternative from peanuts using microwave dehydration. The process involved soaking, removing the skin, grinding, extracting milk, and coagulating with calcium salts. The final product closely mimicked conventional paneer in texture and taste, highlighting the potential of peanuts as a plant-based alternative [27].

Mounsey and O'Riordan explored the use of different nuts, such as peanuts, cashews, macadamias, and almonds, in producing non-dairy cheese and paneer substitutes. These nut-based alternatives provide a nutritious and flexible option for individuals with dietary restrictions, allergies, or those following a plant-based lifestyle, expanding choices beyond traditional dairy products [9].

3.3 Millet-Based Paneer

Incorporation of Millet Flours into Paneer: Narayananstudied the impact of adding 1% wheat and finger millet (ragi) flours to paneer to boost its fiber content. The findings indicated that the millet-enhanced paneer maintained similar flavor and overall acceptability compared to regular paneer [28].

Development of Millet-Blended Paneer Kheer: Kumar et al. developed a fiber-rich paneer kheer by incorporating foxtail millet (Setariaitalica) flour at varying levels (2%, 3%, and 4%). The study determined that 2% millet flour provided the best sensory experience, enhancing texture, consistency, and imparting a nutty flavor [29].

Optimization of Coagulants in Millet Paneer Production**:** Singh et al. analyzed how different food-grade acids—citric, tartaric, and malic acids—affected the texture and sensory properties of Kodo millet (Paspalum scrobiculatum) paneer. The results showed that higher acid concentrations negatively influenced both texture and taste, emphasizing the need for careful coagulant selection to maintain product quality [30].

IV. PROTEIN AND FAT QUALITY OF MILK AND PLANT BASED SOURCES

The quality of a dietary protein depends on how well it meets the body's need for essential amino acids. This includes the amino acid composition of the protein as well as how efficiently the body can digest, absorb, and utilize it [31]. One common way to measure protein quality is assessed using the Protein Digestibility Corrected Amino Acid Score (PDCAAS), which measures how well a protein meets essential amino acid needs. This score considers both the protein's amino acid composition and its digestibility. A score below 100% indicates that the protein does not fully meet the body's amino acid needs. Most plant-based proteins tested so far have scores below 100%, meaning they are generally less complete compared to animal proteins. For instance, wheat gluten has a particularly low PDCAAS score of just 25%, making it one of the least effective plant proteins in providing essential amino acids[32].

Table 1: Protein and fat quality of milk and plant based sources

Source	Protein	Protein Digestibility (%)	PDCAAS	DIAAS	Fat	Reference
Animal source						
Milk	3.2	96	100	114	4.1	[32]
Plant source						
Soy	43.2	98	100	-	19.7	[33]
Green lentil	25.1	84	63	65	0.7	[32]
Yellow split pea	24.5	88	64	73	1.2	[32]
Green pea	7.2	99	89	58	1.6	[34]
Chickpea	17.1	89	74	82	5.3	[32]
Oilseeds source						
Peanuts	25.3	-	52	-	40	[32]
Coconut	3.4	-	-	-	41	[34]

V. PROPERTIES OF DAIRY AND VEGAN PANEER

5.1 Physicochemical properties

Physicochemical properties refer to the physical and chemical attributes of food materials that impact their behavior during processing, storage, and consumption [35].

5.1.1Texture Profile Analysis (TPA)

Texture Profile Analysis (TPA) is a widely used method for evaluating the textural qualities of food products, including paneer. This technique provides a quantitative assessment of various textural parameters, which are crucial for determining quality, consumer acceptance, and culinary applications. Typically, a texture analyzer measures properties such as resilience, gumminess, chewiness, cohesiveness, hardness, and springiness [36].

Table 2: Texture profile analysis of dairy and vegan paneer

	Firmness (g)	Stickiness (g mm)	Elasticity (mm)	Binding capacity	Toughness (g)	Masticability (g mm)
Milk Paneer	3221 ± 59d	−22.4 ± 4.8a	0.47 ± 0.03c	0.42 ± 0.02d	1416 ± 58d	657 ± 21e
Pea paneer	1096 ± 23a	−4.32 ± 1.5c	0.21 ± 0.01a	0.22 ± 0.01a	332 ± 27a	93 ± 6a
Tofu	1375 ±82c	-	4.90 ± 0.23 b	0.71 ± 0.01 b	998.00 ± 28d	4809.75 ± 35.5
Reference : [37, 38]						

5.1.2 Bulk density

Bulk density is a crucial physicochemical property of paneer that affects its texture, quality, and overall consumer acceptance. It is defined as the mass per unit volume of paneer and is typically expressed in grams per cubic centimeter (g/cc). This property plays a significant role in determining the firmness and mouthfeel of paneer, influencing its suitability for various culinary applications [39].

Table 3: Bulk density analysis of dairy paneer

Pressure (kg/cm^2)	Pressing Duration (min)	Bulk Density (g/cc)
3.0	10	1.03
3.0	15	1.08
4.0	10	1.05
4.0	15	1.07
5.0	10	1.10
5.0	15	1.36
Reference: [40]		

5.2 Functional Attributes

Vegan paneer exhibits distinct functional properties compared to dairy paneer due to differences in protein structure. These variations influence key attributes such as heat resistance and moisture retention. Water holding capacity impacts the texture and juiciness of the final product, influencing its ability to retain moisture during preparation. These factors play a crucial role in shaping the sensory and culinary performance of vegan paneer in various dishes [40].

VI. CHALLENGES OF VEGAN PANEER

The rising consumer demand for dairy-free cheese alternatives, driven by health benefits and market trends, has attracted significant entrepreneurial interest. However, achieving broad acceptance remains a challenge [41]. Key efforts must focus on educating consumers about the benefits of these products, addressing concerns about taste and quality, and refining formulations to replicate the sensory attributes of traditional cheese. One major hurdle is replicating the desired texture and flavor, as plant-based proteins often impact sensory appeal. This highlights the importance of continued research and innovation to enhance mouthfeel, texture, and overall consumer experience [2]. Researchers are exploring novel formulations and processing techniques to overcome these challenges. By improving the sensory qualities of dairy-free cheese using innovative plant-based ingredients, manufacturers can better align with consumer expectations, boosting market adoption and investment in this growing sector [38].

VII. ADVANTAGES AND DISADVANTAGES OF VEGAN PANEER

Advantages
Numerous studies indicate that a vegan diet can significantly lower the risk of conditions like cardiovascular diseases, obesity, and certain cancers. Long-term adherence promotes overall health [6].
Diets based on plants can enhance blood sugar regulation and improve insulin sensitivity,making them beneficial for diabetes management and individuals with metabolic syndrome [6].
Plant-based diets often utilize fewer environmental resources, reducing the ecological footprint compared to animal agriculture and supporting ethical considerations in food choices [6].
Legumes provide high protein content, fiber, and essential nutrients, and their digestibility can be enhanced through methods like sprouting and fermenting [23].
Fortified plant-based milks offer vital nutrients like calcium, vitamin D, and vitamin B12, and they serve as good dairy alternatives. Varieties like soy and oat milk replicatedairy in flavor and functionality [23].
Disadvantages
Vegan paneer lacks specific proteins and lipids that aid in calcium absorption, which may lead to decreased bone mineral density if not properly fortified with calcium and vitamin D [42].
Essential components such as vitamin B12 and omega-3 fatty acids are often less available in vegan sources, necessitating supplementation or careful dietary planning to prevent deficiencies [43].
The iron content in plant-based sources can be less available for absorption, which may increase the risk of iron deficiency anemia unless paired with vitamin C-rich foods or fortified products to enhance absorption [43].

VIII. POSSIBLE BY PRODUCTS

8.1 Mung bean paneer

The development of hybrid dairy-legume cheese substitutes involves the partial replacement of dairy proteins with legume-based alternatives. This approach offers enhanced nutritional and functional benefits while promoting the creation of more sustainable food products. It also has the potential to expand market opportunities by catering to diverse consumer preferences. A recent study explored the use of plant proteins as a base for developing flavoured cheese with a sensory profile tailored to the tastes of Southeast and East Asian consumers [44]. The research suggested that incorporating proteins commonly found in regional diets could enhance flavour familiarity and acceptance, making these products more appealing [45].

8.2 Coconut milk-based paneer

Current research trends in novel product development are largely influenced by increasing urbanization, which has driven demand for specialty and functional beverages. The physico-chemical, sensory, and nutritional properties of coconut milk and its derivatives, such as coconut yogurt and coconut-based paneer, closely resemble those of cow's milk products.

Derived from a fruit rich in fiber, vitamin C, and essential minerals, coconut milk is naturally lactose-free and contains easily digestible medium-chain triglycerides (MCTs) that support weight management. Additionally, coconut milk has been linked to increased high-density lipoprotein (HDL) cholesterol, which benefits cardiovascular health. Its lauric acid content also exhibits antibacterial, antiviral, and anti-inflammatory properties [46].

8.3 Synbiotic millet paneer

Synbiotic millet paneer is an innovative dairy alternative designed to improve both nutritional value and gut health [50]. A study by [46] explored the production of this paneer by fermenting millet flour with specific probiotic strains, resulting in a product that not only mimics the texture of traditional paneer but also provides the health benefits of probiotics. The study emphasized that millet, a gluten-free grain, is rich in essential nutrients such as

vitamins, fiber, and protein, making it suitable for individuals with dietary restrictions. Additionally, the inclusion of probiotics in the fermentation process supports a healthy gut microbiome, potentially enhancing digestive health. This novel product offers a versatile ingredient for various culinary applications, appealing to health-conscious consumers seeking sustainable food choices [44].

8.4 Millet milk-based powder

The millet milk powder developed in this invention is composed of sucrose, millet, honey, and fresh milk[47]. Its primary benefits include a calorie content of 383 kcal[48] and a carbohydrate content of 78%, making it nutritionally comparable to dairy milk[49]. It also contains 0.9% crude fiber, which is higher than that of dairy milk but lower than coconut milk [50]. Additionally, it has a higher protein content (7-8%) and fat content (0.6–0.7%)[51]. The study found that when stored at low temperatures, the viscosity of millet milk decreases while total soluble solids increase[52]. Drum-dried millet milk was observed to have a high protein content of 8.57%, whereas malted millet milk was characterized by lower fat and higher fiber and protein level [47].

8.5 Fermented millet milk beverage

[48] developed a fermented beverage by blending skim milk with millet milk in three different ratios (25:75, 50:50, and 75:25). The millets were first sprouted separately and then combined with the milk mixture. A 2% starter culture was added, and the mixture was heated at 37°C for 12 hours to facilitate fermentation. During this period, the milk was left undisturbed to ensure proper curdling. Once fermentation was complete, the curd was blended using an electric mixer, with salt and spices added as needed. The study also evaluated consumer perception based on different millet and skim milk combinations. More recently, [49,50] examined the nutritional, physical, and organoleptic properties of millet-based milk following malting. The kodo millet-based milk beverage contained 1.75 g of protein, 15 °Brix TSS, 0.86 acidity, 3.26 g of total sugar, 5.73 g of starch, and 1.79 g of reducing sugar per 100 g. The study found that sprouting millet reduced viscosity and sedimentation while enhancing milk yield [53].

IX. CONCLUSION

Vegan paneer presents a promising alternative to traditional dairy products, but several challenges hinder its widespread adoption. One of the primary obstacles is replicating the sensory qualities of dairy paneer, as differences in taste and texture often lead to consumer skepticism. Nutritional gaps, particularly in essential proteins, vitamin B12, and omega-3 fatty acids, further complicate its suitability as a sole dietary option, necessitating careful supplementation and dietary planning. Additionally, while plant-based diets are generally more sustainable, concerns arise regarding the environmental impact of monoculture farming and the carbon footprint associated with ingredient sourcing and transportation. These factors must be critically assessed to ensure that the ecological benefits of vegan paneer outweigh its drawbacks. The market for vegan paneer also faces intense competition from various dairy alternatives, making consumer engagement and market penetration more challenging. To address these limitations, innovative formulations, fortification strategies, and sustainable agricultural practices are essential. Ongoing research and development efforts should focus on enhancing vegan paneer's nutritional profile and sensory attributes to align with consumer expectations. Furthermore, increasing consumer education and awareness about the benefits and potential of plant-based alternatives will be crucial for their broader acceptance in mainstream diets.

ACKNOWLEDGEMENT

The authors are grateful to the Department of Food Technology and Research Department(Seed money project) , Ramaiah University of Applied Sciences, Bengaluru, India.

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International Journal of Environment, Agriculture and Biotechnology
Vol-10, Issue-3; May-Jun, 2025
Peer-Reviewed International Journal
Journal Home Page Available: https://ijeab.com/
Journal DOI: 10.22161/ijeab

Development and Performance Evaluation of Solar Power Operated Brush Cutter

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Received: 30 Mar 2025; Received in revised form: 28 Apr 2025; Accepted: 06 May 2025; Available online: 11 May 2025

Abstract— *The solar power-operated brush cutter offers a promising solution for sustainable agriculture, emphasizing reduced environmental impact and cost-effectiveness. Its design prioritizes performance, reliability, and user-friendliness, with carefully selected components ensuring optimal functionality under diverse conditions. This solar-powered solution showcases the feasibility and effectiveness of clean energy technologies in agriculture, promoting a greener and more sustainable future for farming practices. The solar power operated brush cutter consists of Main frame, Ground Wheel, Handle, Switch, Solar Panel, Motor, Battery, Inverter, Cutting Blade. The developed solar power operated brush cutter performance evaluation was carried out calculated theoretical field capacity (ha/h), actual field capacity (ha/h), Field efficiency (%) cutting efficiency and power consumption.*

Keywords— ***solar power, brush cutter, sustainable agriculture, field efficiency, clean energy.***

I. INTRODUCTION

Grass growth in India is influenced by a combination of factors including diverse climatic conditions, varying soil types, seasonal rainfall patterns, and agricultural practices. In tropical regions like the south, species like Bermuda grass and Kikuyu grass thrive in high temperatures, while temperate zones in the north favor grasses like Kentucky bluegrass and fescue. Soil quality, ranging from fertile alluvial soils to lateritic soils, also impacts grass growth, with well drained soils supporting healthy vegetation. Rainfall, influenced by the monsoon, dictates the lushness of grasslands, with heavy rainfall promoting growth and dry seasons leading to dormancy.

Indian livestock industry is growing at a fast rate and contributing 31.6% to the national agricultural gross domestic product. India produces nearly 22% of global milk with Cumulative Annual Growth Rate of around 6.35% in the last 5 years. According to NITI Ayog, milk production in the country can go up to 330 MMT by 2034. Livestock census trend indicates that the number of cross bred female cattle has increased by 43.6% and the female buffaloes have increased by 12.71% in the last 7 years indicating higher demand for quality feed and fodder. In the farm maintenance of a dairy, it is estimated that feed and fodder cost is around 65%. However, the country is facing 23.4% deficit in dry fodder and 11.24% deficit in green fodder. A number of technologies have been developed for fodder production, preservation and assessment of animal feed requirement. There is a vast scope of private investment and development of small business models in the sector. New ideas, technologies and capitals are required in a mode that can be utilized to cater to the needs of rural business involving SHG, women, youth (male and female) and developing suitable models in the form of start-ups, entrepreneurship, enterprises etc (Sai Krishna. *et al*.2024)

The area under fodders is around 9.0 million ha, which account for 4.8-5% of the total area under cultivation in the country. The area under permanent pasture and other grazing land is around 15 million ha. At present the country faces a shortage of green fodder, dry fodder and concentrates. Estimates vary from agency to agency and

methods of estimation; some agencies put it at a net deficit of 35 % green fodder, 11 % dry forages, and 44 % concentrates. One recent study by the ICAR-AICRP on Forage Crops, considering the factors of the animal census and dry, green and concentrates requirement of animals based on their age, sex, mulching, work nature etc. has estimated 23% deficit in dry fodder and 11% deficit in green fodder.

over the last three decades, the paddy cultivation area in Andhra Pradesh decreased by 24.4 percent, with a Compound Annual Growth Rate (CAGR) of -0.43%, and production increased by 22.9% (CAGR of 0.76%). The annual average productivity increased by 62.6%, with a CAGR of 1.27%.

At present, in India, this crop is harvested manually with a sickle in majority of small holding farms and the crop is left in the field in the form of heaps for 7–10 days for sun drying. After sun drying, the crop is threshed with a suitable thresher [3]. The adoption of high level of mechanization like combine harvester may lead to improve cropping intensity and productivity which may incur high fuel consumption. However, promotion of ecofriendly agricultural implements and machinery are increasing with the aim of optimal-utilization of the available sources with a reduced drudgery level at various agricultural operations [4]. Eco friendly technology and alternate power sources are the identified mechanization gaps for small farm mechanization [5]. In India, small and marginal farmers are the most vulnerable to climate change and price inflation. Hence, the development of electric energy-based, smaller equipment for harvesting the crop can help them to make agriculture sustainable in both ways, i.e., economically and environmentally. It is also stated that any modification that can increase fuel efficiency or that may cut down fuel consumption and reduce CO2 emissions may result in reduction of energy consumption and environmental pollution, thereby contributing to cleaner production [6]. Presently, engine operated brush cutters are well popular among farmers for various operations like paddy harvesting [7], grass cutting, etc. The portable harvester (brush cutter) developed for wheat worked satisfactorily with an average value of 1.23% for post-harvesting losses with the actual field capacity of 0.038 ha/h and the field efficiency was 62.99% [8]. Many researchers are modifying the brush cutter ergonomically for multipurpose operations.

II. MATERIALS AND METHODS

The various factors involved such as collection of anthropometric dimensions of agricultural workers, design, development and conducting experiments regarding cutting operation in well prepared field. For the fabrication of the solar power operated brush cutter, the workshop facility of the siddharth institute of engineering technology, puttur was used. In the month of March 2024, the brush cutter was tested from mechanical point of view. The developed brush cutter was tested under field condition.

2.1 Development of solar operated brush cutter

The commercially available petrol engine operated brush cutters are used mostly for plant cutting operations carried out in agricultural fields, thus they prevalent among the Indian small farmers. Development of Solar Power Operated Brush Cutter The developed solar power operated brush cutter consists of Main Frame, Ground Wheel, Handle, Cutting Blade, D.C Motor, Power Transmission Unit, Solar Photovoltaic Panel, Battery, Power Management System (Control Panel, Inverter, Ammeter, Switch).

The main frame in a solar power-operated brush cutter serves as the backbone of the entire machine, playing a pivotal role in ensuring structural integrity, stability, and functionality. Its importance lies in providing robust support for critical components such as the cutting mechanism, motor, solar panels, and energy storage systems. Finally a prototype was developed as shown in Fig. 2.2.

2.2 Ground wheel

Ground wheel of 220 mm diameter was used to support the motor and its mounting frame. Mild steel round bar of 8 mm diameter was used for the fabrication of ground wheel. The ground wheel, usually located at the base of the brush cutter, helps stabilize the machine during operation. It ensures that the cutter maintains a consistent height above the ground,

Fig.2.1. Ground wheel

2.3 Handel

A standard light weight M.S. 27.5 mm outside diameter conduit pipe is used for handle of the tool carrier. Length of handle is calculated based on average standing elbow height of female worker. Average standing elbow height of women workers is 100 cm.

2.4 Solar photovoltaic panel

Solar photovoltaic panels are integral components of solar power-operated grass cutters, harnessing the sun's energy to provide sustainable power for these devices. A Solar photovoltaic panel provided at the top of the sprayer on inclined position to collect solar rays and converts into electrical energy. This electricity was then connected to a 12Volts12Amperessealed Lead acid battery via charging circuit. This battery stores DC electricity and gives power supply to a dc motor which directly drives a sprayer pump assembly.

Battery In a solar-powered grass cutter, the battery serves as a crucial component, acting as the energy reservoir that stores electricity generated by the solar panels during periods of sunlight. The Battery is an electric device that is used to store current which is produced from the solar panel and supplied to the corresponding loads. The number of batteries required depends on the load requirement.

2.5 DC Motor and Micro controller

A 12V, 200 RPM geared DC motor was used to operate the fertilizer metering shaft. The DC motor was mounted on the frame. The wired connection accomplished from tractor battery through the DC Voltage regulator. Table.1 show specifications of the DC motor.

Table.2.1 specifications of the DC motor

Parameter	Description
Name	xcluma
Type	Geared
Max RPM	200
Min RPM	180
Voltage	12 V
Torque	8.15 kg-cm

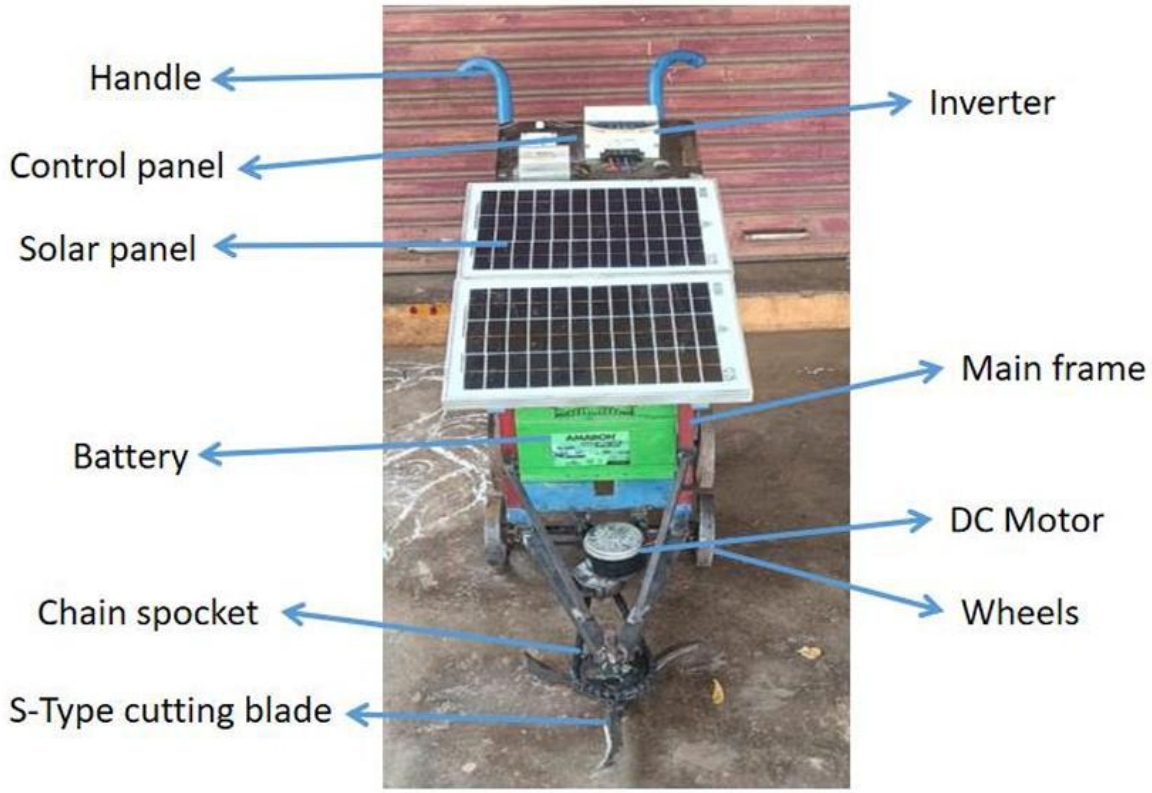

Fig.2.2. Developed solar operated brush cutter

Motor controller A motor controller consists of micro-controller, resistors, sensors, pulse width modulation (PWM) generator circuit, MOSFET, signal acquisition and processing circuit, over-current and under-voltage protection circuit etc. PWM generator which gives voltage from 12 to 24 volt was used in the prototype to control the

rotational speed of cutting blade. It gives provision to operate E-brush cutter with variable speed during evaluation.

Chain and Sprocket In a solar power operated grass cutter, the chain and sprocket system play a pivotal role in converting the rotational motion generated by the solar-powered motor into the linear motion necessary for cutting grass effectively. The sprocket, typically attached to the motor shaft, transfers power to the chain, which in turn drives the cutting blades. This mechanism ensures efficient power transmission and precise control over the cutting action, allowing the grass cutter to operate smoothly and effectively.

Experimental design the study was carried out in fodder filed. During evaluation of field two types of blades were used. i.e. (i) S type and, (ii) Stright blade for crop parameters and associated machine performance. The cutting trials were conducted on selected range of cutting blade speed and crop moisture content in controlled field conditions. The details of controlled field condition parameters are given in Table 1. Experimental field trials were conducted in RBD (Randomized Block design) with three replications in the fodder field (100 m^2 for each replication). Details of machine specifications and crop parameter.

Table.2.2. Details of operational and performance parameters for control field condition

Independent variable	levels	Details	Dependent variables
Moisture content	2	40 (M1) and 30 (M2)	Power requirement (W)
Blade speed,	3	40 (S1),60 (S2) and	Actual field capacity (ha/h)
(RPM)		80 (S13)	
Blade shape	2	S type (L1) and Stright blade (L2)	Cutting efficiency (%)

Table.2.3. Detail specifications of engine and electric brush cutter

S. No	Particulars	Dimensions
1	Overall dimension (L×B×H), mm	1920 × 500 × 950
2	Working width, mm	30
3	Number of rotors	1
4	Height of handle from ground, mm	950
5	Number of blades in rotor	Serrated blades - 3
6	Blade thickness, mm	1.4
7	Width of handle, mm	460
8	Size of float (L×B×H), mm	160 × 90

III. RESULTS AND DISCUSSION

The effect of stem moisture content, blade shape and blade speed on all the dependent parameters are mentioned below with the statistical analysis given in Table 2.

3.1 Power requirement, watt (W)

A three-way analysis of variance (ANOVA) was conducted to investigate the effects of Moisture Content, Blade Speed, and Blade Shape on the required Power (kW). The results indicated that all three main effects moisture content, blade speed, and blade shape—had statistically significant influences on power consumption. specifically, blade speed exhibited the most substantial impact ($F = 156.61$, $p < 0.0001$), followed by Blade Shape ($F = 49.00$, $p < 0.0001$) and Moisture Content ($F = 20.64$, $p = 0.0022$). In contrast, the interaction effects between Moisture Content and Blade Speed ($p = 0.7585$), Moisture Content and Blade Shape ($p = 0.9222$), Blade Speed and Blade Shape ($p = 0.3721$), and the three-way interaction among Moisture Content, Blade Speed, and Blade Shape ($p = 0.9959$) were all found to be statistically insignificant. These findings suggest that each factor independently affects power consumption without significant interactive influences. Furthermore, the low error variance relative to the total variance highlights a good model fit. Overall, Blade Speed

emerged as the most critical factor influencing the power requirement, followed by Blade Shape and Moisture Content.

Table 5. ANOVA for effect of independent parameters on power requirement (F and P values)

Source of Variation	SS (Sum of Squares)	df	MS (Mean Square)	F	p-value
Moisture Content (M)	96.04	1	96.04	20.64	0.0022
Blade Speed (S)	1456.71	2	728.35	156.61	<0.0001
Blade Shape (L)	228.04	1	228.04	49.00	<0.0001
M × S (Interaction)	2.71	2	1.35	0.29	0.7585
M × L (Interaction)	0.04	1	0.04	0.01	0.9222
S × L (Interaction)	10.71	2	5.35	1.15	0.3721
M × S × L (Interaction)	0.04	2	0.02	0.004	0.9959
Error	32.67	7	4.67		
Total	1826	17			

3.2 Effective field capacity, ha/h.

A three-way ANOVA was conducted to assess the effects of Moisture Content, Blade Speed, and Blade Shape on Field Capacity (ha/h). The analysis revealed that all three main effects were statistically significant. Moisture Content showed a significant effect on field capacity ($F = 15.97$, $p = 0.0047$), indicating that changes in moisture level substantially influence field performance. Blade Speed had the most prominent impact ($F = 28.08$, $p = 0.0004$), suggesting that adjusting the rotational speed of the blades greatly enhances field capacity. Additionally, Blade Shape significantly affected field capacity ($F = 6.74$, $p = 0.0362$). Conversely, all interaction terms including Moisture Content × Blade Speed, Moisture Content × Blade Shape, Blade Speed × Blade Shape, and the three-way interaction were statistically insignificant ($p > 0.05$), implying that each factor operates independently without notable combined effects.

Table 6. ANOVA for effect of independent parameters on field capacity

(F and P values)

Source of Variation	SS (Sum of Squares)	df	MS (Mean Square)	F	p-value
Moisture Content (M)	0.000102	1	0.000102	15.97	0.0047
Blade Speed (S)	0.000358	2	0.000179	28.08	0.0004
Blade Shape (L)	0.000043	1	0.000043	6.74	0.0362
M × S (Interaction)	0.000011	2	0.000006	0.94	0.4290
M × L (Interaction)	0.000001	1	0.000001	0.18	0.6860
S × L (Interaction)	0.000008	2	0.000004	0.66	0.5430
M × S × L (Interaction)	0.000001	2	0.0000005	0.09	0.9120
Error	0.000045	7	0.0000064		
Total	0.000568	17			

The relatively small error variance relative to the total variance suggests that the model fits the data well. Overall, Blade Speed emerged as the most critical factor, followed by Moisture Content and Blade Shape, in optimizing the field capacity.

3.3 Graphical Representation of effect of operational parameters

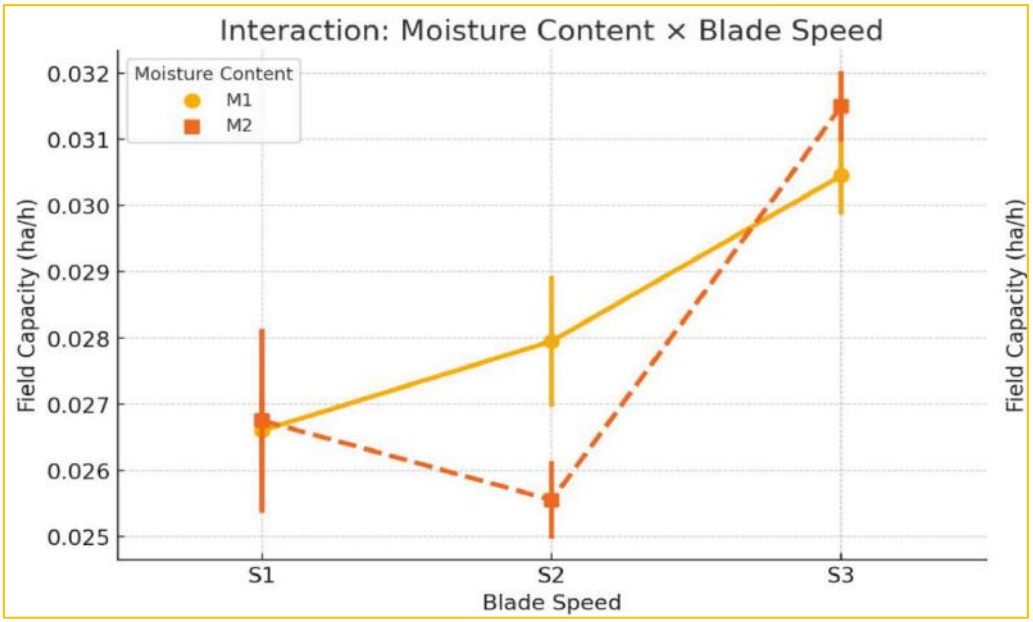

Fig.2.1. Moisture content and blade speed effect on field capacity

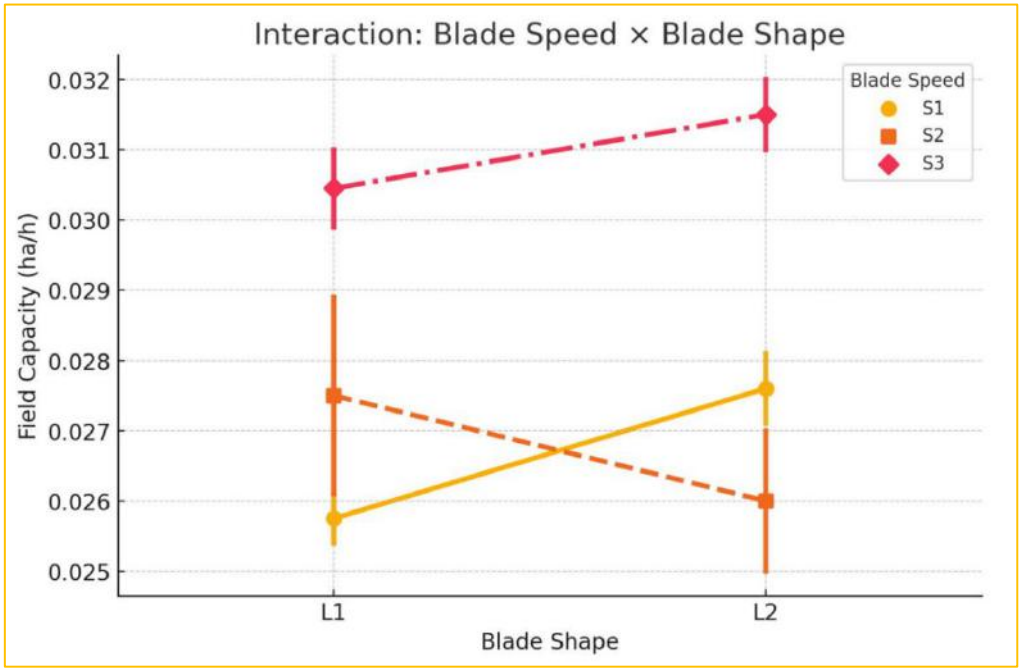

Fig.2.2. Blade speed and blade shape effect on field capacity

3.3 Cutting Efficiency (%)

The results of statistical analysis showed that harvesting machine had significant impact on cutting efficiency. The crop standing status and its interaction had non-significant effect on cutting efficiency. The mean cutting efficiency of 85 % and 90.67 % was observed for electric brush cutter at regular field conditions, respectively. compare with traditional method higher cutting efficiency was observed.

IV. CONCLUSIONS

A battery-operated electric brush cutter was designed and evaluated in this study with the primary aim of minimizing fuel usage and lowering operational costs. The performance analysis revealed that blade speed, stem diameter, and moisture content significantly influenced the power requirement. The cutter required an average total power of 1826 W. The electric brush cutter achieved a maximum cutting efficiency of 90.67%. Field trials highlighted the electric model's strong potential as a sustainable alternative, offering considerable fuel savings, reduced operational costs, and elimination of direct exhaust emissions. Furthermore, the ergonomic design helped reduce user fatigue and hand-arm vibration compared to traditional engine-driven units. This makes the electric brush cutter particularly well-suited for small-scale farming operations. Nevertheless, future research should focus on integrating long-duration batteries to further enhance its practicality and adoption.

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International Journal of Environment, Agriculture and Biotechnology
Vol-10, Issue-3; May-Jun, 2025
Peer-Reviewed International Journal
Journal Home Page Available: https://ijeab.com/
Journal DOI: 10.22161/ijeab

Effect of feeding mustard cake on nutrient utilization in Pratapdhan chicks

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Received: 05 Apr 2025; Received in revised form: 01 May 2025; Accepted: 08 May 2025; Available online: 13 May 2025

Abstract— *The present study was designed to assess the effect of feeding mustard cake on nutrient utilization in Pratapdhan chicks. A total of 200 day-old straight run Pratapdhan chicks were randomly divided into four treatment groups with five replicates of 10 chicks each. The chicks were fed maize soyabean deoiled cake basal diet (T1, control) or with mustard cake included at 3% (T2), 6% (T3 and 9% (T4) in the diet replacing soya DOC by 10, 13, and 16%. A metabolism trial was conducted at 8 weeks of age to study nutrient utilization by Pratapdhan chicks. Results showed that supplementation of 6% Mustard cake in the diet significantly improved the CF intake, digestible CF intake in Pratapdhan chicks. The digestibility coefficients of crude protein (80.48%), crude fibre (76.54%), ether extract (84.65%) and NFE (75.94%) were significantly (P<0.01) higher in T3 compared to other treatments while digestibility remained lowest in control group. The protein and energy efficiency ratios were significantly (P<0.01) higher in T3 (1.94 and 13.90) compared to other treatment groups. Based on results of nutrient utilization it can be concluded that Mustard cake can be safely included in the diet of Pratapdhan chicks at 6 percent level for better digestibility of pratapdhan chicks.*

Keywords— ***Pratapdhan, Mustard cake, Digestibility coefficient***

I. INTRODUCTION

Poultry sector plays an important role carries a pivotal position in current Indian economy and has evolved as an extremely business oriented enterprise (Sreenivas *et al*., 2013). The total poultry population in the country has increased by 16.81% over the previous census i.e. 2012 (BAHS, 2019). India ranks 7th in the world poultry population at 851.81 million (BAHS, 2019), 2nd largest producer of eggs with total production of 142.77 billion eggs, and 5th in meat production with 10.25 million tonnes meat in 2023-24. The per capita availability of is only 103 eggs and 7.39 kg meat per year (2023-24) which is far apart the level of 180 eggs per head per year and 10.5 kg of meat recommended by the ICMR, Govt. of India. Economically poultry meat and eggs are acquiring popularity due to its high nutritional value. Poultry meat is a nutritious food for children, young, adult and old people. It contains high quality protein having all the essential amino acids in abundance for optimum human nutrition.

Among the vegetable protein sources soybean deoiled cake is the most commonly used protein source. Mustard or rapeseed is among the major oilseeds in the world, and belongs to the genus '*Brassica*' Mustard oil cake is a fairly good source of protein (31 to 39%) and energy (2200 kcal/kg), low in lysine (1.0 to 2%), but rich in methionine (1.01 to 1.57 %) compared to SBM (Vaidya *et al.*, 1979). Mustard cake is one of such vegetable protein which has relatively better composition of amino acid, however, utilization of mustard oil cake in poultry diets is limited due to the presence of certain intrinsic toxic principals (Vaidya *et al*., 1979; Prasad and Rao, 1982a), which are known to lower the performance of birds when used at higher levels (>10%) in the diets of chicken (Vaidya *et al.*, 1979; Prasad and Rao, 1982a; Mc Neill and

Mac Leods, (2001). The information effect of feeding mustard cake on nutrient utilization in poultry is relatively limited and information on indigenous or improved chicken is scanty. The present study is a part of the research work carried out to study the effect of feeding mustard cake on growth performance and nutrient utilization in Pratapdhan chick.

II. MATERIAL AND METHODS

Experimental birds, diet and management

Two hundred Pratapdhan chicks were randomly divided into four different groups consisting of five replicates of 10 chicks each and fed four dietary treatments containing maize soybean deoiled cake diets supplemented with mustard cake at 0, 3, 6 and 9% levels in the diet. The diets contained composition mixture of maize, soya deoiled cake, deoiled rice bran and vitamin premix with mustard cake at different levels.

Pratapdhan chicks were procured from Hatchery of Poultry Farm, Department of Livestock Production Management, Rajasthan College of Agriculture, Udaipur. The chicks were reared under strict hygienic condition in the brooder house of the AICRP on Poultry Breeding, Poultry Farm, Department of Animal Production, Rajasthan College of Agriculture, Udaipur. Before housing the chicks, experimental brooder rooms, equipment and utensils were cleaned and disinfected thoroughly with phenol and fumigated with formaldehyde gas. The chicks (day old) were weighed at the beginning of the experiment and randomly divided into 4 groups. Rice husk was used as bedding material, thickness of bedding material was kept 2 inches initially which were subsequently increased by 0.5 inch. The chicks were vaccinated against Ranikhet, Marek's and Infectious Bursal Disease (IBD).

A metabolism trial was conducted at the end of the experiment i.e. 8 weeks of age to study nutrient utilization. Two birds from each replicate in a treatment were randomly selected and shifted to metabolic cage. Thus, a total of 10 birds from each treatment were used for metabolism trial. During three days collection period quantity of feed offered, feed left over and excreta voided were recorded and taken for nutrient analysis. The proximate principles were estimated as per AOAC (2005). The protein efficiency ratio was calculated by following formula

$$\text{Protein efficiency ratio} = \frac{\text{Weight gain (g)}}{Total\ Protien\ intake\ (g)}$$

The energy efficiency ratio (EER) was calculated using following formula

$$\text{Energy efficiency ratio} = \frac{\text{Total Weight gain (g)}}{Total\ Metabolizeable\ Energy\ intake} X100$$

Statistical methods

The experimental design was conducted in completely randomized design (CRD) and the data pertaining to various parameters obtained during growth, metabolic trial of the present study was analyzed by analysis of variance described by (Snedecor and Cochran, 1994).

III. RESULTS

Nutrient intake

A metabolism trial was conducted at the end of the feeding trial after 8th weeks of age. The data pertaining to nutrient intake and utilization is presented in Table1.

The data pertaining nutrient intake and digestible nutrient intake is presented in Table 1. The difference in mean dry matter intake, crude protein intake, Ether extract intake and NFE intake amongst different groups was found to be small and statistically non-significant. However, the crude fibre intake and digestible crude fibre intake were significantly (P<0.01) higher in T4 as compared to other treatments groups which may be due to inclusion of mustard cake at higher level.

Table-1. Effect of feeding of mustard cake on nutrient intake in Pratapdhan chicks

Particulars	T1	T2	T3	T4	SEm	CD
DM Intake (g/bird/d)	67.02±1.56	65.69±1.47	66.12±1.01	66.07±1.13	1.31	NS
Digestible DMI (g/bird/d)	46.59±1.48	46.16±1.54	45.75±0.21	46.62±1.11	1.21	NS
CP intake(g/bird/d)	13.53±0.31	13.03±0.29	13.31±0.20	13.52±0.23	0.26	NS
Digestible CP intake(g/bird/d)	10.31±0.30	10.07±0.30	10.71±0.21	10.62±0.23	0.26	NS
CF intake(g/bird/d)	1.59^{c}±0.04	1.51^{c}±0.03	1.77^{b}±0.03	2.08^{a}±0.04	0.03	0.11**

Particulars	T1	T2	T3	T4	SEm	CD
Digestible CF intake(g/bird/d)	1.23^{c}±0.04	1.20^{c}±0.03	1.49^{b}±0.03	1.73^{a}±0.04	0.03	0.11**
EE intake(g/bird/d)	2.65±0.06	2.79±0.06	2.66±0.04	2.56±0.04	0.05	NS
Digestible EE intake(g/bird/d)	1.89±0.06	2.04±0.06	1.99±0.03	1.89±0.04	0.05	NS
NFE Intake(g/bird/d)	47.17±1.10	46.42±1.04	46.35±0.71	45.78±0.78	0.92	NS
Digestible NFE intake(g/bird/d)	34.24±1.05	34.65±1.08	35.20±0.56	34.33±0.77	0.89	NS
Nitrogen intake(g/bird/d)	2.16±0.05	2.08±0.05	2.13±0.03	2.16±0.04	0.04	NS
Nitrogen balance(g/bird/d)	1.69±0.05	1.57±0.04	1.71±0.03	1.70±0.04	0.04	NS

The mean nitrogen balances (g/bird/day) were 1.69±0.05, 1.57±0.04, 1.71±0.03 and 1.70±0.04 g in T1, T2, T3 and T4 groups respectively. The difference in nitrogen balance amongst different groups was also found to be statistically non-significant.

Nutrient utilization

The data with respect to digestibility coefficients of nutrients as influenced by feeding of mustard cake at different levels is presented in Table 2. The mean digestibility coefficients of dry matter was found to be non-significant amongst different treatment groups. The digestibility coefficients of CP, CF, EE and NFE were significantly (P<0.01) higher in T3 as compared to other treatment groups. the groups supplemented with mustard cake at 6% recorded highest digestibility coefficients of CP (80.48%), CF (76.54%), EE (84.65%) and NFE (75.94%). The digestibility of all the nutrients was found to be higher in group containing mustard cake at 6%. The digestibility coefficient was lowest in control group.

Table-2. Effect of feeding of mustard cake on nutrient digestibility coefficient in Pratapdhan chicks

Particulars	T1	T2	T3	T4	SEm	CD
DM	69.49±0.59	70.24±0.76	69.22±1.10	70.54±0.48	0.77	NS
CP	76.20^{c}±0.46	77.26^{b}±0.58	80.48^{a}±0.36	78.55^{b}±0.35	0.45	1.46**
CF	71.03^{c}±0.56	72.97^{b}±0.69	76.54^{a}±0.43	73.66^{b}±0.43	0.54	1.76**
EE	77.34^{d}±0.44	79.69^{c}±0.52	84.65^{a}±0.28	82.89^{b}±0.28	0.39	1.29**
NFE	72.57^{b}±0.53	74.62^{a}±0.65	75.94^{a}±0.30	74.96^{a}±0.41	0.49	1.60**
Total Protein intake (g)	353.75^{c} ±0.66	365.89^{a} ±0.62	352.86^{c} ±1.22	358.08^{b} ±1.36	1.02	3.06**
Protein Efficiency Ratio	1.47^{c} ±0.01	1.69^{b} ±0.05	1.94^{a} ±0.01	1.62^{b} ±0.05	0.04	0.11**
Total ME intake (Kcal)	4939.20^{b} ±17.94	5194.10^{a} ±52.83	4933.17^{b} ±15.32	4977.41^{b} ±12.43	22.64	67.88**
EER	10.53^{c}±0.03	11.94^{b}±0.50	13.90^{a}±0.03	11.68^{b}±0.12	0.25	0.74**

**P<0.01

Means bearing different superscripts in a row differ significantly.

The protein efficiency ratio was also calculated and values were 1.47±0.01, 1.69±0.05, 1.94±0.01and 1.62±0.05 in T1, T2, T3 and T4 respectively. It was found the data that the protein efficiency ratio was significantly highest (P<0.01) in T3 followed by T2, T4 and lowest in T1. The difference in protein efficiency ratio in T2 and T4 remained at par with each other.

The total metabolizable energy intake for the entire experimental period was calculated by multiplying total feed intake with ME content of the diets and the total mean ME intakes were 4939.20±17.94, 5194.10±52.83, 4933.17±15.32 and 4977.41±12.43 Kcal in T1, T2, T3 and T4 groups respectively. The overall body weight gains up

to 8th weeks of age were 520.14±1.25, 619.94±6.25, 685.83±1.82 and 581.53±4.74 g in T1, T2, T3 and T4 groups respectively.

The energy efficiency ratio was also calculated and values were 10.53±0.03, 11.94±0.50, 13.90±0.03 and 11.68±0.12 in T1, T2, T3 and T4 respectively. It was found the data that the energy efficiency ratio was significantly highest (P<0.01) in T3 followed by T2, T4 and lowest in T1. The difference in protein efficiency ratio between T2 and T4 was found to be small and statistically non-significant.

IV. DISCUSSION

Banday *et al.* (2003) fed rape seed meal (RSM) with CuSO4.5H2O (4g/kg feed) and FeSO4.7H2O (l0g/kg feed) separately or in combination without or with supplemental iodine @ 6.67mg/kg RSM and incorporated in the diet at 15 per cent level for part of the soybean meal and de-oiled rice bran fed to three hundred per replicate. There was a significant (P<0.05) improvement in the digestibility of different nutrients due to chemical processing of RSM with higher retention of various nutrients in the birds. It can be concluded that chemical processing of RSM was effective in detoxifying the RSM to a considerable extent that treated meal could be beneficially utilized as a protein supplement up to 15 per cent in the diet of broiler chicken up to 42 days age.

Thacker and Petri (2011) found that the digestibility of dry matter, energy and phosphorus increased linearly (P<0.01) with increasing levels of canola protein concentrate. Although nutrient digestibility was higher for birds fed diets due to containing canola protein concentrate, these improvements did not translate into improvements in broiler performance.

Ivkovic *et al.* (2012) in a study three groups formed and fed either with corn-soy based diet (control group) or with inclusion of 10% (RSM 10%) or 15% of rapeseed meal (RSM 15%), respectively. No significant differences (P>0.05) were observed in any measured digestibility parameter. However, in present study the digestibility of nutrient was significantly higher in group fed mustard cake at 6% level.

Sonowal *et al.* (2018) fed untreated and copper sulfate treated mustard oil cake at 0, 10, 15 and 20% to broiler chicken for a period of six weeks and found no significant effect of supplementation of mustard oil cake with or without treatment on digestibility of nutrients. However in present study mustard cake 6% improved digestibility of nutrients.

Smulikowska *et al.* (2006) in an experiment of broiler chicks fed rapeseed expeller cake and extruded cake at 10 and 15% of the diet in three phases, it was found that the apparent protein digestibility, nitrogen retention, organic matter retention, apparent metabolizable energy value and energy metabolizability were lower while fat digestibility was higher in RCE than in RC. The results of the present study are in agreement with the findings.

Mohanta *et al.* (2022) conducted a study to evaluate the performance of indigenous Nusuri chicken germplasm of Odisha maintained in floor rearing system. Seventy birds were selected for this study. Body weight, feed consumption, feed conversion ratio (FCR), energy efficiency ratio (EER) and protein efficiency ratio (PER) were calculated up to 20 weeks of age. The mean cumulative EER and PER was 9.07 and 1.23 at 8th week respectively. The highest and lowest protein efficiency ratio in the present study was 1.94 and 1.47 while the highest and lowest energy efficiency ratio was 13.90 and 10.53 respectively. The higher efficiency of protein as well as energy in the present study may be attributed to genetic inheritance of the birds, in present study Pratapdhan an improved chicken was used as compared to indigenous chicken in the study by Mohanta *et al.* (2022) with slower growth rate.

Zahid Kamran *et al.* (2008) found that total protein intake was decreased (P<0.01) and protein efficiency ratio was increased (P<0.01) linearly with low CP diets. In the present study the protein and energy efficiency ratio was increased in the diets supplemented with mustard cake at 6% as compared to other dietary treatments.

V. CONCLUSION

The mean digestibility of nutrients such as CP, EE, CF and NFE were significantly higher in T3 group which was fed mustard cake at 6% of the diet as compared to other groups. In the present study the protein and energy efficiency ratio was also increased in the diets supplemented with mustard cake at 6% as compared to other dietary treatments.

ACKNOWLEDGMENT

The authors are thankful ICAR-AICRP on Poultry Breeding project for providing facilities during the experiment and to Head, Department of Animal Production, for providing their infrastructure and facilities in carrying out the research work.

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International Journal of Environment, Agriculture and Biotechnology
Vol-10, Issue-3; May-Jun, 2025
Peer-Reviewed International Journal
Journal Home Page Available: https://ijeab.com/
Journal DOI: 10.22161/ijeab

Constraints faced by goat keepers in Rajsamand district of Rajasthan

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Received: 03 Apr 2025; Received in revised form: 03 May 2025; Accepted: 09 May 2025; Available online: 14 May 2025

Abstract**—** *The aim of the present study was to find out the constraints faced by goat keepers in the Rajsamand district of Rajasthan. In this study, four tehsils were selected, namely Rajsamand, Nathdwara, Deogarh, and Kumbhalgarh, based on their high goat populations. From each tehsil, five villages were randomly chosen, and 10 respondents with at least ten goats were surveyed from each village, totaling 200 respondents. Data was collected using a pre-tested, well-structured interview schedule. The present study showed that 69.5% of respondents faced severe constraints, with 12% experiencing the most severe and 18.5% experiencing the least severe constraints. The main constraints identified were grazing land shortage (MPS: 94.16), lack of veterinary services (MPS: 91.5), and insufficient credit facilities (MPS: 87). Other significant constraints included a shortage of feed and fodder (MPS: 85.33), non-availability of green fodder (MPS: 80.5), and a lack of knowledge regarding the selection of breeding bucks (MPS: 78.16). Additional issues were a lack of knowledge about scientific goat housing (MPS: 73.33), the high cost of breeding bucks (MPS: 71.5), the high price of concentrate feed (MPS: 69.66), and a lack of knowledge about balanced feeding (MPS: 65.5). Further constraints included a lack of knowledge about mineral mixture feeding (MPS: 62.33), the high price of mineral mixtures (MPS: 61.16), low productivity of goats (MPS: 59.16), parasitic problems (MPS: 54.83), and a lack of knowledge about deworming (MPS: 50.16). Based on the findings, it is recommended to develop appropriate strategies for the advancement of goat farming and support for goat farmers.*

Keywords**— Goat keepers, Constraints, Rajsamand**

I. INTRODUCTION

The goat species holds significant importance in the country's livestock sector due to its short generation intervals, high rates of prolificacy, and the ease of marketing both the goats and their various products. These products include meat, milk, skin, and fiber. In regions such as arid, semi-arid, hilly, heavy rainfall, and tribal areas, goats are of great economic value as they can survive on minimal forage and in extreme climatic conditions where other animal species may struggle. The country is also known for its high-quality leather production from goats, making it a leading exporter of goatskin. Furthermore, there is a possibility of exporting non-traditional goat products like cheese and goat milk powder, which have limited domestic demand (*Dixit et al.*, 2009). As of 2019, India's goat population was 148.88 million, constituting 27.8% of the total livestock. Rajasthan leads in goat population with 20.84 million goats (BAHS, 2019). In 2022-23, the country produced 230.58 million tonnes of milk, with goat milk contributing 3.30% to the total. Additionally, the total meat production was 9.77 million tonnes during the same period, with goat meat accounting for 14.47% (BAHS, 2023). The goat is an important species of livestock that holds special significance in the ecology of southern Rajasthan. This is primarily due to the fact that commercial dairy farming and other cash crops are not economically feasible,

especially in the Southern Region. Goat rearing serves as a major source of economic sustenance for marginal farmers and landless laborers in Rajasthan. Rajasthan is home to six recognized breeds of goats, namely Sirohi, Marwari, Jhakrana, Sojat, Karauli and Gujari, in addition to a large population of non-descriptive goats. Goat farming is a significant agricultural activity in Rajsamand district. It is a common practice in both marble and non-marble areas of the district. Farmers in these regions raise goats for meat and milk production. In marble areas, farmers face challenges such as limited grazing land due to marble quarries. The presence of marble in an area has an impact on goat grazing. Goats find it difficult to graze on areas with a lot of marble due to the hard and rocky surface. This limits the availability of grass and plants for the goats to feed on. Recognizing and addressing the primary constraints of goat farming facilitates easier adoption for goat farmers. Therefore, the present study was conducted to examine the various constraints faced by goat farmers in Rajsamand district.

II. MATERIALS AND METHODS

The present study was conducted in Rajsamand district of Rajasthan. Four tehsils- Rajsamand, Nathdwara, Deogarh, and Kumbhalgarh-were selected from the district. From each tehsil, five villages were chosen randomly, and 10 respondents who owned at least ten goats were selected from each village. Data was collected from 200 goat farmers through personal interviews using a pre-tested, well-structured interview schedule. The collected data was analyzed using simple statistical techniques including frequency, percentage, mean score, and MPS (mean percent score). The identified constraints were assessed on a 3-point scale: most serious constraint (scored as 3), severe constraint (scored as 2), and less severe constraint (scored as 1). Scores for each constraint were aggregated to obtain a total constraints score. Based on these scores, the constraints were ranked accordingly.

Percentage and frequency

This approach involved calculating the percentage and frequency distribution of goat farmers, enabling the categorization of goat farmers accordingly.

Mean score

It was obtained by dividing total score of each statement by total number of respondents.

$$Mean\ Score = \frac{Total\ Score\ of\ each\ Statement}{Total\ number\ of\ respondents}$$

Mean percent score (MPS)

Mean percent scores were obtained by multiplying total obtained score of the respondents by hundred and divided by the maximum obtainable score under each practice. Formula of MPS is given under:

$$MPS = \frac{\text{Total score obtained by the respondent}}{\text{Maximum obtainable scores}}$$

Rank

The ranking was done in descending order based on the mean percentage score received. This process helped identify the severity of constraints in a specific order of priority.

III. RESULTS AND DISCUSSION

Level of constraints

The results of the level of constraints presented in Table 1 indicated that the majority (69.5%) of respondents faced severe constraints. Additionally, 12% faced the most severe level of constraints, while (18.5%) faced the least severe constraints in the study area. The findings are in line with the results obtained by Kavithaa *et al.* (2020), who revealed that the majority (53.34%) of the respondents had a medium level of constraints followed by high (33.33%) and low (13.33%) level constraints in dairy farming activities.

Table 1: Distribution of respondents on the basis of level of constraints (n=200)

S.No	Constraints level	Rajsamand		Nathdwara		Deogarh		Kumbhalgarh		Total	
		F	%	F	%	F	%	F	%	F	%
1.	Least severe (<65.00)	5	10	8	16	10	20	14	28	37	18.5
2.	Severe (65-79)	43	86	38	76	33	66	25	50	139	69.5
3.	Most severe(>79)	2	4	4	8	7	14	11	22	24	12
	Total	50	100	50	100	50	100	50	100	200	100

n= number of respondent, F= frequency, % = per cent

Types of constraints being faced by goat keepers

The results of type of constraints presented in Table 2 indicated that the goat rearers identified shortage of grazing land as the foremost constraint, with an MPS value of 94.16, making it the top-ranked constraint. The findings are in line with the results obtained by Singh *et al.* (2018), who reported that the majority of goat farmers (95.6%) and sheep farmers (92.6%) identified lack of grazing land as the main issue.

The lack of veterinary services in the village is ranked as the second most serious constraint, with an MPS value of 91.5. Similar findings were reported by Halpati *et al.* (2023), who reported that the primary health constraints were the lack of health services in the study area, with a mean score of 68.65 (I).

The lack of credit facilities ranked as the third most pressing constraint, with an MPS value of 87. The results are supported by Sorathiya *et al.* (2016), who reported that top socio-economic constraints included a lack of credit facilities and high wage rates in Valsad and Navsari districts of south Gujarat.

The shortage of feed and fodder was considered the fourth most significant constraint, with an MPS value of 85.33. These findings are in line with the findings of Tudu and Roy (2015), who revealed that both the scarcity of feed and grasses were major constraints faced by goat farmers.

The non-availability of green fodder was recognized as the fifth serious constraint in the study area, with an MPS value of 80.5. The results of the present investigation are in consonance with Gamit *et al.* (2020), who reported that the majority of respondents identified the lack of availability of green fodder (75.83%) as the most important feeding constraint faced by goat keepers in the study area.

The MPS score for the constraint of lack of knowledge regarding the selection of breeding bucks was calculated to be 78.16, placing it in sixth place, the lack of knowledge about scientific goat housing was identified as the seventh serious constraint, scoring an MPS value of 73.33 and the high cost of breeding bucks ranked as the eighth most critical constraint within the examined region, receiving an MPS value of 71.5. Similar findings were reported by Kakraliya *et al.* (2022), who revealed that the high cost of breeding bucks (MPS=92.13), lack of knowledge regarding the selection of breeding bucks (MPS=86.11), lack of knowledge about scientific goat housing (MPS=62.18) were major constraints faced by goat keepers in the study region.

The high price of concentrate feed was recognized as the ninth critical constraint, registering an MPS score of 69.66. The results are in line with the observation of Sabapara *et al.* (2014), who reported that among different constraints related to feeding, high prices of concentrate (89.60%) appeared at first rank.

The lack of knowledge of balanced feeding ranked as the tenth most critical constraint within the examined region, receiving an MPS value of 65.5. The results of the present investigation are in consonance with Tanwar (2011), who reported that among different constraints related to feeding, 94.17% (ranked 1st) of farmers were ignorant about balanced feeding for their goats.

Table 2: Type of Constraints faced by goat keepers in Rajsamand district of Rajasthan (n=200)

S.No	Constraints	MPS	Rank
1.	Lack of credit facility	87	III
2.	Non-availability of green fodder	80.5	V
3.	Shortage of feed and fodder	85.33	IV
4.	High price of concentrate	69.66	IX
5.	Shortage of grazing land	94.16	I
6.	High price of mineral mixture	61.16	XII
7.	Lack of knowledge about feeding of mineral mixtures	62.33	XI
8.	Lack of knowledge about balance feeding	65.5	X
9.	Lack of knowledge about deworming	50.16	XV
10.	Lack of veterinary services in the village	91.5	II
11	Parasitic problems in goat	54.83	XIV
12.	Lack of knowledge about scientific goat housing	73.33	VII
13.	Lack of knowledge regarding selection of breeding buck	78.16	VI
14.	Low productivity of local goats	59.16	XIII

15.	High cost of breeding bucks	71.5	VIII
MPS= Mean per cent score			

The issue of lack of knowledge about mineral mixture feeding was the eleventh most critical constraint in the examined region, scoring an MPS value of 62.33, the high price of mineral mixtures ranked as the twelve most pressing constraint, with an MPS value of 61.16 and the MPS score for the constraint related to the low productivity of goats was computed as 59.16, indicating its thirteenth position in the ranking. Similar findings were reported by Kakraliya *et al.* (2022), who revealed that the lack of knowledge about mineral mixture (MPS 91.66), the high price of mineral mixture (MPS= 80.00) and low productivity of local breeds was also causing concern to a significant number of respondents (MPS=72.44) in Sirohi tehsil of Sirohi district of Rajasthan.

The issue of parasitic problems in goats was identified as the fourteenth most significant constraint in the examined region, with an MPS value of 54.83. Similar findings were reported by Sabapara *et al.* (2014), who revealed that lack of parasitic problems in goats (73.20%) was the significant constraint faced by goat farmers in the Navsari district of Gujarat.

The lack of knowledge about deworming; it was the fifteenth most pressing constraint with an MPS score of 50.16. The present findings are supported by Gamit *et al.* (2020), who reported that the lack of knowledge on the importance of deworming (43.33%) is a significant constraint faced by goat keepers in Saurashtra, Gujarat.

IV. CONCLUSION

From the present study, it was concluded that most respondents (69.5%) faced severe constraints, with the main issues being a shortage of grazing land (MPS: 94.16), a lack of veterinary services (MPS: 91.5) and insufficient credit facilities (MPS: 87). To address the identified constraints in the study area, technical and institutional intervention is required. This can be achieved through the dissemination of appropriate technologies and extension strategies for better feeding, improved goat breed supply and improved access to feed and fodder as well as their conservation .Ultimately, these measures will enhance goat farming and boost goat farmers income.

ACKNOWLEDGMENTS

The authors express their gratitude to Dr. Siddhartha Mishra who made his immense contribution in my research work.

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International Journal of Environment, Agriculture and Biotechnology
Vol-10, Issue-3; May-Jun, 2025
Peer-Reviewed International Journal
Journal Home Page Available: https://ijeab.com/
Journal DOI: 10.22161/ijeab

Colonial Scientific Forestry and its Challenges: The Creation of Forest Reserves and Local Resistance in the Gambia

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Received: 10 Apr 2025; Received in revised form: 06 May 2025; Accepted: 11 May 2025; Available online: 15 May 2025

Abstract— *Forest reserves were central to the sustainable management of forest resources within colonial territories, which is not any different in the Gambia. However, there is little or no evidence on colonial scientific forestry and its challenges with respect to the creation of forest reserves and local resistance in the Gambia. The study adopted a systematic review of the literature, which used the Preferred Items for Reporting Systematic Review and Meta-analyses (PRISMA) to select sixteen (16) studies. The study showed that the main aim of colonial scientific forestry was to rationalise forest management through mapping, classification, and conservation of timber resources for colonial economic interests. The study found that forest reserves restricted local access to vital land and forest resources, which were often culturally significant. The study revealed that the barrier to sustainably implementing scientific forestry was largely due to underfunding, weak institutional capacity, and external pressure from timber and agricultural sectors. The findings showed that colonial policies in the Gambia laid the groundwork for continued centralised governance, but recent shifts favour participatory and hybrid models. The study concludes that the implementation of forest reserves, while justified under the guise of ecological conservation, served more to reinforce colonial authority and economic interests at the expense of indigenous land rights and cultural practices.*

Keywords— ***Colonial scientific forestry, forest reserves, local resistance, forestry, forest management***

I. INTRODUCTION

Over time, colonial scientific forestry emerged as a dominant strategy for forest management in many parts of the British Empire during the 19th and early 20th centuries. With an ideal rooted in European forestry traditions, scientific forestry was premised on the rational and sustainable exploitation of forest resources through demarcation, classification, mapping, and centralised control. Contextually, the introduction of scientific forestry in the Gambia during the late colonial period brought with it a fundamental shift in land use, access, and ecological governance. Forest reserves were established with the intention of preserving valuable timber resources, preventing deforestation, and generating economic benefits for the colonial administration. However, these policies often clash with existing local practices, livelihoods, and cultural values tied to the land.

Kumar (2012) referred to colonial scientific forestry as the process by which the colonial state applied scientific forestry techniques to increase the potential for forest regeneration and productivity. It was stated further that this process can be either conservatively oriented or exploitative, which is used to exploit forest resources with the least amount of conflict with populations that depends on them, rather than solely for conservation and exploitation. Mizuno (2022a) noted that there are several types of colonial forestry method, and it was suggested that the forestry system was limited by the political and ecological circumstances of each region, which result in a hybrid form. Furthermore, it is important to acknowledge the influence of interactions between states and local

governments, as well as their evolving relationships. Mizuno (2022b) notes that some projects combined contemporary methods with indigenous knowledge and customs from colonial forestry.

Recently in a study by Asiyanbi (2025), it was established that decolonizing forestry, especially in countries that were under the British colonial rule, is a precondition for saving its last rainforest. The study indicates that factors such as reductionist understanding of trees, capitalist interests, and a racially global division of labour all interacted to a significant extent in colonial forestry. This is same as what is obtainable in the contemporary carbon forestry of this age. Vandergeest and Lee Peluso (2006) underscored that, after World War Two, post-colonial organisations like the FAO made it easier to build forestry as a sort of empire, even if colonial forestry established some management systems that were continued after colonialism ended. They further accentuated that only when colonialism ended did forestry emerge as the largest landowner in the area. This however came with its attendant challenges, which are varying and diverse.

There are several challenges of colonial scientific forestry. Sunseri (2005) assumes that forestry had to adjust to particular challenges since, like other areas of the colonial government, it was supposed to be self-sufficient. These include determining which forests in a sizeable area with underdeveloped infrastructure could be profitably managed. Movuh (2012) notes that since community forestry seeks to involve the local population in forest management, which helps redress their historical exclusion due to colonial policy, the colonial history presents a unique challenge. Hansen and Lund (2017) indicate that colonial scientific forestry faced challenges in its implementation due to economic constraints and industry pressure. This leads to the collapse of scientific management, which gives way to unsustainable timber extraction. Some of the undermining sustainability efforts and weakening enforcement of conservation policies include low stumpage fees and export levies, set far below international timber prices, and sever limited available funds for effective forest management (Messenger, 2024).

Furthermore, there has been no strategic management plans and adequate protection of forests, which has led to the forbidden of access to these forests with the exception of “right of passage” and “restricted advantages”. Nevertheless, the locals gained unauthorised access to the reserved forests for agricultural purposes and wood harvesting, even with the security architecture put in place (Kobbail, 2011). Basyuni et al. (2025) recommended regular monitoring of forest reserves, but cautioned that this may be met with challenges of long-term monitoring, which include seasonal fluctuations and difficulty in identifying morphologically similar species. Other challenges identified by Basyuni et al. (2025) include limited funding, ecological and taxonomic expertise, and the need for interdisciplinary collaborations for proper implementation. This is because there is a need for concerted among stakeholders who are of different expertise. Their continuous engagement would help enhance the continuous monitoring to overcome these challenges. Meanwhile, colonial scientific forestry led to the creation of forest reserves, which disregards local land use and spark resistance from communities excluded from forest access (Grove, 2017).

Forest reserves were central to the sustainable management of forest resources within colonial territories, which is not any different in the Gambia. Hölzl (2010) notes that the British forestry tradition is rooted in the 19th Century European scientific and administrative thinking, wherein scientific forestry sought to apply methodological planning, classification, and exploitation of forests to meet economic or strategic needs of colonial administration. Thus, forest reserves emerged, not only as a tool of ecological regulation, but to serve as instrument for imperial control, revenue generation, and territorial reordering. Meanwhile, the creation of forest reserves under colonial scientific forestry was to guide against deforestation and forest degradation caused by shifting cultivation, uncontrolled logging, and local community use (Enuoh & Bisong, 2015). The British colonial leaders believed that local land use practices were destructive and primitive, which often overlook the in-depth ecological knowledge and sustainable traditions embedded in indigenous systems (Johnston, 2022). Thus, forest reserves were mapped, demarcated, and gazette by colonial authorities to restrict access to valuable timber species, control land use, and regulate extraction activities.

During the colonial period in the Gambia, forest reserves were viewed as repositories of economic wealth to enhance export-oriented timber industries and they are often placed under strict supervision to minimise what colonial officials labelled as “encroachment”. However, the transformation of forest landscapes into state-controlled reserves introduced several contradictions (Karsenty, 2016; Molander, 2014). While the essence of scientific forestry is to support sustainability and long-term productivity, its implementation in colonial context often deviated from these core principles (Hölzl, 2010). Economic pressures, administrative limitations, and industry lobbying undermined sustainability goals with respect to forest reserves in the colonial Gambia (Manneh, 2023). Based on this, forest reserves became more of

zones for intensive extraction with little or no regard for ecological regeneration instead of being a managed conservation (Götmark, 2013).

Meanwhile, the creation of forest reserves often led to local resistance in some instances. This is because some indigenous communities that had long depended on forest lands for different survival reasons like firewood fetching, food, medicine, and spiritual practices may find themselves being shortchanged (Peres, 2011). Moreover, with the introduction of forest reserves, the customary land rights would be overridden by colonial legal frameworks, which redefine forests as state property. Thus, many local people in the indigenous communities may engage in some forms of resistance. This resistance may be in the areas of illegal logging, burning forest boundaries, or mobilizing against forest guards and so on (Bulkan, 2017). This may become challenging for the sustainability of the area. Therefore, it becomes imperative to understand colonial scientific forestry and its challenges of power, identity, and survival in the colonial Gambia. The study's research questions are as follows:

i. What were the key objectives of colonial scientific forestry introduced in Gambia?
ii. How did the creation of forest reserves during the colonial period in the Gambia impact local indigene's access to forest resources?
iii. What are the challenges that impede the implementation of colonial scientific forestry in the Gambia?
iv. How did local indigene or communities resist the establishment of colonial forest reserves in the Gambia?
v. How colonial forestry polices in the colonial Gambia shape post-colonial forest governance and conservation practices?

II. METHODOLOGY

Using the systematic review approach, this study seeks to understand colonial scientific forestry and its challenges from the perspectives of the creation of forest reserves and local resistance in the Gambia. The systematic review approach allows for structured synthesis of the literature in the focused area, which allows for methodological approach to answering identified of questions (Schut et al., 2024). This aids repeatability and credibility, which enhances the transparency of the study. This approach is often used because it offers precise and illustrative guide that improve the accuracy of the findings, which is not obtainable in a narrative review. Meanwhile, some set of databases were consulted for this study owing to their relatedness with the studied area and the high probability of retrieving relevant literature from the databases. The databases consulted include Scopus, Web of Science, Taylor and Francis, Emerald, Sage, and EBSCOhost.

The study used the appropriate keywords and search terms to enhance the retrieval of relevant literature that would answer the identified research questions of the study (Atkinson & Cipriani, 2018). The databases consulted were with a focus on the sample, phenomenon of interest, design evaluation, and research type (SPIDER) search technique (see Table 1). The reason for this is that the study is quite epochal and may need to focus on either quantitative or qualitative studies, or mixed methods. The SPIDER strategy is considered appropriate for this study as it seeks to allow for wider reach and studies (Hammarberg et al., 2016). This is due to the need to allow for a comprehensive data or information on colonial scientific forestry and its challenges in the Gambia. Meanwhile, in order to find enough evidence on the studied area, the search techniques involved the use of Boolean operators "AND" and "OR" to broaden the search scope (Schut et al., 2024).

Table 1: SPIDER Tool

SPIDER	Content
Sample	Forest managers, colonial authorities, local communities in the Gambia
Phenomenon of Interest	Colonial scientific forestry
Design	Published literature of both qualitative and mixed-methods research
Evaluation	The creation of forest reserves and local resistance to colonial scientific forestry
Research type	Qualitative and mixed methods research

Source: Author's fieldwork (2025)

The SPIDER framework ensured a structured approach to understand the issue of the creation of forest reserves and local resistance in the Gambia to colonial scientific forestry. Using the SPIDER tool in the search query produced a large number of hits/results. Subsequently, inclusion and exclusion criteria were introduced, which appraise the search results to produce only the most relevant studies to the review (see Table 2). The criteria considered in the selection process of the final selected articles include studies published in any period.

This is because the current study is epochal in nature and studies of any period may be of significant relevance or usefulness. Meanwhile, duplicated publications were expunged and those published in other languages other than English were deleted. Also, the studies selected are both primary and secondary research studies. This is because the current study is more of historical study and secondary research study may be of relevance to answer the research findings. Using all these inclusion and exclusion criteria, the final selected literature for this study is sixteen (16).

Table 2: Inclusion and Exclusion Criteria

Inclusion and exclusion criteria	No. of hits	Justifications for search criteria
Studies published (without year range)	895	This is to ensure that all relevant historical studies during the colonial rule in the Gambia can be retrieved
Duplicate publications removed	452	This is to avoid redundancy in the retrieved literature
Literature published in English language	450	This is to ensure that all the literature are in understandable language to allow analaysis
Both primary and secondary research	350	This is to have both primary and secondary research findings
Studies focusing on colonial forestry in the Gambia	50	This is to contextualise the literature analysis to studies that focused on the Gambia
Full-text only	35	Full-text allows critical review and analysis of the literature
Qualitative or mixed-methods research only	16	This is to analyse research findings that provide deeper understanding of experience, phenomenon, and context.

Source: Author's fieldwork (2025)

Meanwhile, the data collection process was ensured in similar structured manner through Preferred Reporting Items for Systematic Review and Meta-analyses (PRISMA) (see Fig. 1). The framework is appropriate for systematic review studies, which is one this study adopted. Meanwhile, the framework has four (4) phases, which include identification, screening, eligibility, and included. In the initial search of the different databases, a total of 895 items were extracted from the different databases. After this, duplications were checked and only 443 items from the collected data were expunged as having duplicates in the returns. Next, the titles and abstracts of the articles were checked for relevance and whether they are relatable to the current study, and only two (2) articles were removed. After all these, the remaining items were examined with the inclusion and exclusion criteria that were set for the study. From this, only sixteen (16) articles were finally selected for this study. These sixteen (16) articles serve as the datasets for the study. Moreover, the collected data were extracted on a data extraction sheet (see Appendix I). Data analysis was conducted using the "a priori" thematic analysis.

III. RESULTS AND DISCUSSION

On the objectives of colonial scientific forestry introduced in the Gambia, the study showed that the main aim of colonial scientific forestry was to rationalise forest management through mapping, classification, and conservation of timber resources for colonial economic interests. This theme is evident in two of the final selected sixteen (16) literature, which include Saidykhan (2023) and Sillah (1999). These studies (Saidykhan, 2023; Sillah, 1999) demonstrated that colonial conservation was introduced alongside agricultural expansion but often contradicted extraction practices. Similarly, Fanneh (2020) shows that British trade in legumes and grains led to policies influencing forest governance indirectly through infrastructural and economic development. These studies primarily used archival and historical research approaches, which draw on colonial documents, trade records, and administrative reports to establish the theoretical and policy basis of scientific forestry.

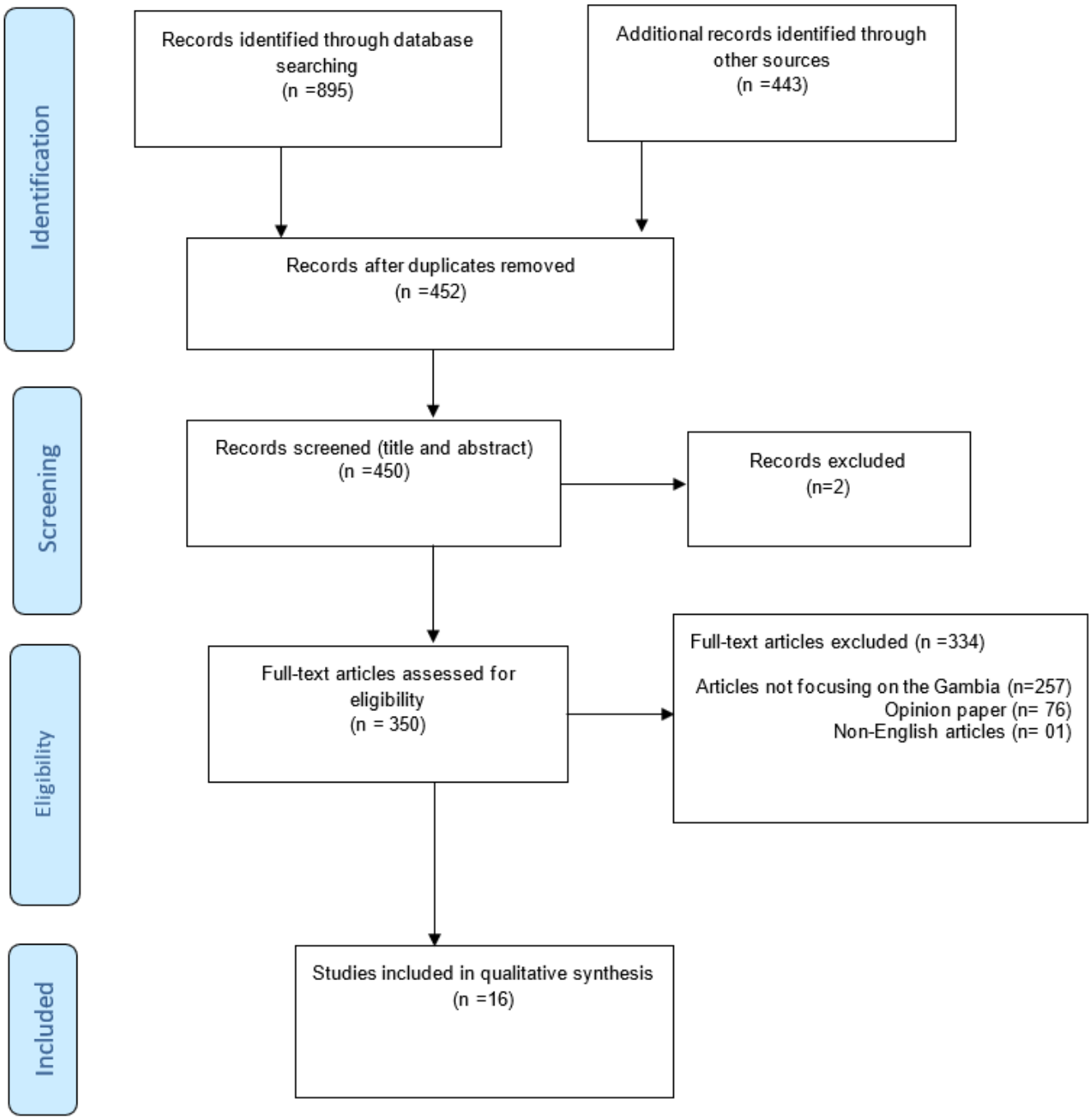

Fig.1: PRISMA Framework

On how the creation of forest reserves during the colonial period impact local communities' access to forest; forest reserves restricted local access to vital land and forest resources, which were often culturally significant. Two of the final selected studies (Darboe, 2023; Darboe et al., 2023) demonstrated communities viewed forests as essential to their livelihood, well-being, and cultural identity. This indicates that local communities in the Gambia viewed forest reserves as instrumental to personal and cultural development. Also, Sillah (1999) emphasises how forest reserves pushed agricultural activities into marginal lands, exacerbating ecological pressure and inequality in land access. These three studies (Darboe, 2023; Darboe et al., 2023; Sillah, 1999) used qualitative and ethnographic methods, which include interviews and GIS analysis to document the experiences and perceptions of communities directly affected by forest reserves.

On the challenges that impede the implementation of colonial scientific forestry in the Gambia, it was

revealed that the barrier to sustainably implement scientific forestry was largely due to underfunding, weak institutional capacity, and external pressure from timber and agricultural sectors. Gunnarsson and Bergman (2010) identified the lack of effective knowledge dissemination and mistrust of government forestry programs as challenges. Two of the studies (Schroeder, 1997; Tomaselli et al., 2012) highlight that resource constraints and corruption in forest enterprises, which reveal inefficiencies in governance. These three studies (Gunnarsson & Bergman, 2010; Schroeder, 1997; Tomaselli et al., 2012) combined archival, qualitative, and case study approaches, which often incorporate oral histories, interviews, and participatory insights to expose structural weaknesses in implementation.

On how did local indigene or communities resist the establishment of colonial forest reserves in the Gambia, the findings showed that local resistance ranged from passive non-compliance to active contestation. Two of the studies (Schroeder, 1999; Symington, 2015) showed that communities used gendered land claims, traditional rites, and community-based conservation as resistance tools. This indicates that cultural factors are significant when it concerns local resistance of forest reserves. Madge (1995) emphasises indigenous forest regulation by rural women, which highlight local resistance through daily practice and informal management. These studies (Madge, 1995; Schroeder, 1999; Symington, 2015) relied on ethnographic and exploratory research designs, which prioritise in-depth, localised accounts of resistance through cultural and gendered lenses.

Table 3: Tabular Representation of the Final Selected Literature

Methodology	Key studies	Focus
Historical/Archival	Fanneh (2020), Sillah (1999), Manneh (2023)	Colonial policy formation, trade, and land transformation
Qualitative	Darboe (2023), Darboe et al. (2023), Tomaselli et al. (2012)	Community perspectives, socio-economic impacts, governance
Exploratory/ethnographic	Madge (1995), Schroeder (1999), Saidykhan (2023)	Local resistance, cultural knowledge, gendered responses
Mixed/participatory	Norikane (2007), Sanneh (2023)	Customary tenure, natural regeneration, hybrid governance

Source: Author's Fieldowrk (2025)

On how colonial forestry policies in the Ghana shape post-colonial forest governance and conservation practices, the findings showed that colonial policies in the Gambia laid the groundwork for continued centralised governance, but recent shifts favour participatory and hybrid models. For instance, Norikane (2017) discusses the incorporation of customary tenure systems, and Sanneh (2023) evaluates assisted natural regeneration as a post-colonial intervention rooted in past forest management failures. Evans (2022) shows how colonial era patterns of exploitation and border insecurity continue to affect forest governance today. These studies (Evans, 2022; Norikane, 2017; Sanneh) used mixed methods and case studies, which emphasise institutional analysis, stakeholder engagement, and longitudinal environmental tracking.

Implications

The findings contribute to the theoretical understanding of colonial environmental governance, especially in relation to scientific forestry and its socio-political ramifications. Colonial scientific forestry has often been portrayed in the literature as a rational and ecologically-driven model aimed at conserving forest resource. However, this study challenges that narrative providing contradictions in the implementation of scientific forestry in the Gambia. It emphasises that colonial forestry policies were shaped not only by environmental considerations but also by economic exploitation and imperial control. The theory of political ecology is relevant as it provides the intersection of power, resource control, and environmental narratives. This supports the argument that colonial forest reserves functioned as instruments of dispossession rather than conservation. The study also shows the limitations of top-down environmental governance where local ecological knowledge and land use practices are deeply embedded in cultural and spiritual life.

Practically, the study underscores the need for inclusive and participatory approaches in forest management and conservation planning. The study shows that the exclusion of local communities from forest governance under colonial scientific forestry led to local resistance and undermined the legitimacy and

effectiveness of conservation policies. For contemporary forest managers, the study offer important insights with respect to imposition of policies without consulting the local community. It emphasised that failure to recognise traditional land rights is possibly going to lead to resistance and non-compliance. Also, the integration of indigenous knowledge systems and respecting cultural values associated with forests can enhance the sustainability and acceptance of conservation initiatives. Forest reserves should no longer be treated as zones of resource control, but as living landscapes with social, spiritual, and economic significance for local population.

With respect to societal implications, this study highlights the long-term social consequences of colonial forest policies and the importance of addressing historical injustices in environmental governance. The creation of forest reserves in the Gambia during the colonial period disrupted local livelihoods, cultural practices, and land tenure systems, which lead to marginalisation and conflict. These legacies continue to influence how communities perceive conservation efforts and interact with state institution today. The study also contributes to broader discussions about environmental justice, which emphasise that sustainable development must be grounded in the principles of fairness, inclusion, and historical awareness. In postcolonial societies like the Gambia, where land and resource rights remain contentious, which revisit colonial environmental histories can inform more just and effective policy-making. In addition, the study encourages civil society, educators, and policymakers to engage in public education campaigns that promote awareness of the cultural and historical dimensions of environmental issues.

IV. CONCLUSION

The study explored the complexities of colonial scientific forestry in the Gambia, which focuses on the creation of forest reserves and the resulting local resistance. The study used a systematic review of literature, through the combination of archival, ethnographic, and qualitative analyses to show that what was portrayed as scientific and sustainable management was, in practice, an extractive and exclusionary approach to forest governance. The study established that the implementation of forest reserves, while justified under the guise of ecological conservation, served more to reinforce colonial authority and economic interests at the expense of indigenous land rights and cultural practices. Local communities, far from being passive recipients of these changes, actively resisted through various forms of social, cultural, and environmental defiance. The study emphasises the importance of recognising these historical dynamics in contemporary forest management, where the legacies of colonial policies still shape access, governance, and resistance. It calls for a more inclusive, historically informed approach to conservation that integrates local knowledge, supports community-based management, and rectifies past injustices. Therefore, the study not only contributes to academic discourse in environmental history and political ecology but also offers insights for creating equitable and sustainable environmental policies in the Gambia and other postcolonial contexts.

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APPENDIX

DATA EXTRACTION TOOL

Colonial Scientific Forestry and its Challenges: The Creation of Forest Reserves and Local Resistance in the Gambia

S/N	Research titles and authors	Aims	Study location (Country)	Methodology	Findings
1	"Re-claiming" land in the Gambia: Gendered property rights and environmental intervention Schroeder (1999)	The study examined gendered property rights and environmental intervention in the Gambia	The Gambia	Historical research approach.	- The study demonstrate how women market gardeners pressed "secondary" usufruct rights to great advantage to ease the economic impact of persistent drought conditions for the better part of a decade, only to have male lineage heads and community leaders "re-claim" the resources in question through donor-generated agroforestry and soil and water management projects.
2	Island Citizens: Environment, Infrastructure, and Belonging in Colonial Gambia, 1816-1965 Manneh (2023)	The study examined environment, infrastructure, and belonging in colonial the Gambia	The Gambia	Archival research approach.	- The study argues that, for the community of formerly enslaved Liberated Africans in The Gambia, participation in colonial political life became contingent upon the ownership of property in the form of dry, reclaimed land carved from mangrove estuaries surrounding the island city of Bathurst. - As this dissertation shows, owning dry land at different points in Bathurst's history marked who could vote in municipal elections, who could be guaranteed British military protection, and who could access financial credit to participate in the colonial economy. - Land reclamation and drainage were therefore not only foundational to Liberated African politics and their claims to autochthony, but also to the origins of Gambian municipal politics and African involvement therein.
3	"The Only Good Crocodile Is A Dead One": Contradictions in Conservation Policies and Agricultural Activities in the Gambia, 1938 -1965 Saidykhan, S. (2023)	This thesis offers new sources that demonstrate how agricultural activities and resource exploitation undermined conservation, and the colonial conservation policies neglected the local ways of forest and wildlife conservation in the Gambia.	The Gambia	Exploratory research approach	- The study shows that the stratified social structure of the Gambian communities balanced the competing interests in the exploitation of forest resources. - It established that the Gambia's major geographic features such as the islands, creeks, and swamps represented a cultural and religious symbol to the communities which protected them from human encroachment and exploitation. - The ritualization of shrines and sacred forests during rites of passage such as childbirth, initiation and death conserved the surrounding flora and fauna.

4	Community-based conservation and development: The case of the Mori Kunda Community Forest in Tujereng, The Gambia Symington (2015)	The study investigates community-based conservation and development in Mori Kunda Community Forest in Tujereng, the Gambia	The Gambia	Archival research approach.	- Community-based conservation (CBC) was developed to synergize social, environmental and economic aspects of conservation by actively involving local communities. To combat deforestation and promote development, The Gambia implemented a Community Forestry Programme (CFP), giving land and resource ownership rights to local communities provided they adopt management responsibilities. - Exploring Tujereng's Mori Kunda Community Forest it was determined that CBC has the potential to result in both development and conservation outcomes. However, outcome extent was dependent upon: incentives; access to land; external training, funding and resources; poverty; competing industries; environmental stewardship; community consultation and values; as well as the communally oriented structure and disposition of Gambian society.
5	Intertwining people and forest in the Lower River Region (LRR) of the Gambia Darboe (2023)	The study examines the interrelationships between the people and forest in the Lower River Region of the Gambia by documenting individuals' life experiences and perceptions about various forest ecosystem services.	The Gambia	Qualitative approach.	- The findings reveal that people's perception about the forest is linked to their well-being and life experience that attributes to their activities of being-in the forest. Those activities contribute to forest development and maintenance through integrated management systems, involving both state and communities in managing what belongs to them. However, from the results, the relationship indicates that humans are the main drivers to deforestation of their community forest. Through their socio-economic and cultural activities like land use change for agriculture, commercial timber production, illegal timber logging, domestic firewood collection and charcoal production, bush fire, human settlement and development.
6	The nature and impact of British involvement in legume and grains trade in the Gambia, 1830-1965 Fanneh (2020)	The study interrogate British involvement in grains trade in the Gambia from 1830 when the first consignment of grains was exported to West Indies to 1965, when the country attained independence	The Gambia	Historical approach and interpretive design. Oral and European documentary sources.	- The paper argues that British involvement in grains trade in the Gambia during the period under examination culminated into series of infrastructural developments that had far-reaching consequences on the country's demography and environment. - British policies on agriculture, taxation and pest control ignited responses such as tax boycotts and refusal to cultivate certain crops from Gambian farmers. Equally, the involvement of European trading companies and merchants with support from the colonial government transformed the nature and volume of the trade. - The development of ports, wharfs, launches and ferry services in addition to road constructions became the dividends of British involvement in the trade in the Gambia. Above all, migrant farmers came from neighbouring countries to grow crops.
7	Restructuring Community Forestry: A Look at	The study examined the tenure, institutions, and	The Gambia	Historical research approach.	- The case study of The Gambia helps to highlight the value of incorporating customary regimes and institutions into forest

	Tenure, Institutions and Gender in The Gambia Norikane (2007)	gender issues in the Gambia regarding restructuring community forestry.			management practices. Through examination of different cultural practices, the case study serves to reinforce some of the notions concerning adaptive tenure and management policies in addition to setting the stage for further discussion into those arenas. - In addition, the recognition of customary and traditional law by the government of The Gambia, as well as pivotal PVO involvement, strengthens forest management institutions in a successful example of hybridization. - Analysis of the Gambian case study provides a platform for community forestry extension in other African countries. Customary institutions should be seen as dynamic and adaptive instruments for management created over time through trial and error by knowledgeable rural experts rather than as the backwards and inflexible creations of the ignorant rural poor.
8	"Forest is integral to life": People-forest relations in the lower river region, the Gambia" Darboe et al. (2023)	The study investigated people-forest relations in the lower river region in the Gambia	The Gambia	The study adopted the qualitative research approach, which allowed for 35 semi-structured interviews. Also, geographic information system (GIS) was used for remote sensing satellite imagery to show baseline for the complex connections and changes.	- The study showed the importance of the forest's contributions to Mandika communities and specifically to their psychological well-being. Also, the interviewees demonstrated how ongoing socio-economic changes are affecting the human-forest relationship and possibly eroding the local ethno-forestry knowledge in lower river region of the Gambia. - The study demonstrated that the most common forest contributions are those that provide material goods, serving as the driving force in connecting people with the forest, while non-material contributions are eroding due to complex socio-economic changes. - The major socio-economic changes are also believed to drive the shift from dense forest to mixed forest and grassland.
9	"Re-claiming" land in the Gambia: Gendered property rights and environmental intervention Schroeder (1997)	The study investigated the impact of ecological policies on commodity production in Gambia where communal market gardens run by women's groups are being converted into privatized orchards managed by male landholders in a state-directed, donor-funded initiative designed to meet stabilization goals.	.The Gambia	Archival research approach	- The economic barriers thrown up by the slow processes of rejuvenation and repair often preclude the prospect of environmental programs paying for themselves outright. Most individual, and many private corporate actors are therefore reluctant to undertake the tasks of reclamation unilaterally. Instead, they default to state functionaries (or their surrogates environmentalists),who confront the production obstacles on their behalf. The state can often alleviate some of the financial burdens of reclamation efforts through regressive taxation or unequal exchange mechanisms, but these tactics have their political and economic limits. Alternatively, state managers can opt for approaches involving coercion or regulatory controls, but these, too, can be quite expensive and are often ineffective due to the political resistance they engender. Consequently, environmentalists develop

					approaches driven by the "positive" incentive of profit-taking associated with commodity production.
10	Forest resources and plantations of the Gambia Sillah (1999)	The study examined forest resources and plantations of the Gambia	The Gambia	Archival research approach.	- The study showed that the major reserves of arable land are be found in the Western and Northern part of the country mainly in former fallow lands. The rest of the arable lands can only be found under forest cover. For this reason, remaining woodlands covering better sites are always attractive as agricultural land with the highest tendency in the west and central part of the country. - Findings showed that in regions that have marginal soils (most parts of the eastern part of the country) seems to have forested lands being already pushed to non-arable sites and fallow lands on marginal sites were recovered back to tree and shrub savannah. - The findings increased demand on wood products in urban and semi-urban areas confirmed the highest decreases of woodlands in these areas compared to the others. This has a direct connection with the population growth of those areas and the socio-economic developments. - Findings showed that the steady diminution of trees on farmlands particularly in the east, leads to increased wind and water erosion and negatively affects the soil water and nutrition cycles; ~the decrease of fallow lands and, thus, shorter fallow periods is wide spread, but more prominent the northern part of the country. - Results showed that the change in tree species composition to more fire resistant species is steadily pushing the natural vegetation woodland species to almost local extinction.
11	Land and historical change in a river valley: property, power and dependency in the lower Gambia basin, nineteenth and early twentieth centuries Sarr (2010)	The study used oral and written sources to explore changing concepts of land tenure along the banks of the lower Gambia River basin.	The Gambia	Archival research sources. Oral and written sources.	- The study shows that landholding customs and land use practices in this region were constantly changing under the impact of new conditions, often related to major historical developments in the area and forces associated with the region's relationship with the wider world, particularly Europe and the Islamic world. - The most important matters affecting land tenure systems were the outbreak of Muslim Revolutions and the development of cash-crop production. - These occurred following the ending of the Atlantic slave trade and, over several decades following 1830, resulted in the overthrow of a Mandinka aristocracy and rejection of royal control over the land.
12	The role of government in the development of small	The study explored the role of government in the	The Gambia.	Qualitative research approach, using multiple	- Data indicate that The Gambian government has had a positive impact on various SMFEs with respect to the transfer of land

	and medium forest enterprises: Case studies from the Gambia Tomaselli et al. (2012)	development of small and medium forest enterprises using case studies from the Gambia.		case study research design.	tenure to local communities, coupled with the implementation of capacity building and support activities. However, there is room for improvement as wood-related enterprises revealed being affected by significant challenges such as corrupt practices, illegal activities and deficient enforcement.
13	Adoption of knowledge related to sustainable forestry from a Gambian perspective Gunnarsson and Bergman (2010)	The paper examines the adoption and diffusion of sustainable forestry related technologies in the Gambia.	The Gambia.	Archival research approach.	- The study found that the ease of the spread of information about locally adopted technologies is crucial. The important role of government departments is confirmed, if a participatory approach and sufficient follow-up are to be observed in the process. However, a certain level of mistrust towards the government is evident in the study. - Village groups are found to be inefficient. Interviews with informed members and NGO staff indicated a cultural norm of keeping knowledge to oneself without spreading it. An alternative approach of targeting dedicated individuals is recommended instead. The result of the study indicates that the adoption of sustainable forestry might not necessarily come with the adoption of improved stoves.
14	Assessing natural regeneration of *Pterocarpus erinaceus* in Kiang West national park, the Gambia Sanneh (2023)	This study aims to determine the impact of ANR on stands of *Pterocarpus erinaceus* in KWNP	The Gambia	Qualitative research approach, using focus group discussion (FGD).	- The findings of the study revealed that on average *Pterocarpus erinaceus* tree density in the ANR plots increased by 100% from 36 trees/ha in 2019 to 72/ha in 2023. In contrast, wildlings density in ANR plots decreased by 44% from 64 trees/ha to 36 tree/ha. The findings also identified fire, overgrazing, illegal logging, termite infestation and drought as the main drivers of degradation in the park. The noticeable increment in the population of *Pterocarpus erinaceus* trees in the study plots implies the effectiveness of ANR as a low-cost landscape restoration strategy being implemented by the EbA project.
15	Insecurity, informal trade and timber trafficking in the Gambia/Casamance borderlands Evans (2022)	The study examines the post-independence period, during which flows of agricultural and forest products mainly from Casamance into the Gambia have continued, while processed foods and manufactured goods have been traded in the other direction.	The Gambia.	Narrative research approach.	- The study showed that certain flows have become pathological since the Casamance rebellion began in 1982, with natural resources being traded by both Senegalese government and separatist forces, and arms trafficked to the latter partly through Gambian channels. With the conflict now of low intensity though not resolved, continued illegal timber exploitation in Casamance driven mainly by international actors is becoming more environmentally destructive and locally divisive. - The study found that informal cross-border trade has long been bound up with insecurity at local, national, transnational and international levels, and that contemporary dynamics show some

					historical continuities.
16	Ethnography and agroforestry research: A case study from the Gambia Madge (1995)	The study examines the contribution that an ethnographic methodology can make to gender-sensitive agroforestry research.	The Gambia.	Ethnography research approach.	- An ethnographic approach is combined with political economy perspectives to illustrate how the significance of such products, particularly for women, has markedly increased during the past two decades, especially for commercial purposes, in response to changing environmental, economic and social circumstances. - Environmental management practices are used by rural individuals to regulate forest resources. Although there is potential for formal management policy to build upon these indigenous practices, a detailed understanding of local human-environmental relationships is essential for any planning mechanism to succeed.

International Journal of Environment, Agriculture and Biotechnology
Vol-10, Issue-3; May-Jun, 2025
Peer-Reviewed International Journal
Journal Home Page Available: https://ijeab.com/
Journal DOI: 10.22161/ijeab

From Lab to Land - Overcoming Challenges in Adoptation of Speed Breeding Technology

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Received: 07 Apr 2025; Received in revised form: 04 May 2025; Accepted: 10 May 2025; Available online: 16 May 2025

Abstract— *As the population of the world is increase day by day, By means adding of population the large failure can occurs in the world among the people's. We' had to break the food scarcity problem before attaining the failure by an system called Speed breeding. Speed breeding is an advanced technology. Introduced by University of Queensland in Australia and inspired by NASA in 2018 in wheat(Triticum aestivium, 2n=42) are grown Wheat on space under controlled environment. This system creates the resistance to biotic and abiotic stress and promote climate adoptability to converting the accelerating the rapid breeding cycle in crops in this technology, numerous kinds can be released in short duration for about 6- 7cycles/ year rather of 3- 4 cycles. Indeed though this veritably important full tool for crop enhancement several barriers are there to adaption this technology. So In my Research I've linked the major barriers which will be in adoptation of speed breeding system among growers, scholars, and agristokeholders. I've used surveying tools like google form and direct check to growers for analysing the data, about 160 samples of response where collected in 3 quarter of villupuram, namakal and chengalpettu among the agrarian collages, research institutions etc. Grounded on this data I've analysed and major barriers and gives the result in my Research. Challenges like high cost, lack of knowledge, limited funding and strategies for overcome from the situation like providing funding, training and workshops ect are discussed in my studied.*

Keywords— ***Adoptation, barriers or challenges, rapid breeding cycle, Overcoming, Speed breeding.***

I. INTRODUCTION

1.1 Background of the study

As we know that numerous advanced technology and styles where used in advancement in Genetics and plant breeding and Biotechnology to accelerate the growth and development of growers and promotes there profitable position in the society By working these kind of problems faced by growers[5] (Jahhans et.al 2023) an new and advanced technology was surfaced in Genetics and plant breeder is called Speed breeding technology[1]. Speed breeding technology was an advanced technology which is used to accelerate the crops breeding cycle rapid than compared to normal breeding(Pasala et.al)[9] . The kinds which was released through speed breeding technology was capability to resistance in biotic and abiotic stress, climate adoptability [2](Askar et.al)and high yield kinds and etc. In this system further than 6- 7 cycles/ time can be achieved compared to normal breeding cycle in crop enhancement[4] (Gautam et.al 2024)so it can give high productivity to growers[5](Begna et.al 2022). These system was performed in artificial growth chamber using high cost outfit setup like LED lights with different wavelength and temperature controller. Artificial Temperature, RH moisture and increase in Co2 position in growth chambers [9].This Speed breeding technology was first introduced in Queensland University in Australia and it was inspired by NASA in 2018 and he'had espoused these technology and had a trail in wheat [13](schoen et. al 2023) crops in space station using a growth chambers in Artificial conditions and that

Research was successful for NASA and numerous exploration institutions and University has slightly adopt these in India and other countries. These was only practices in top Ranking and institutions in Lab and exploration purpose only, some varieties has been released using these method in wheat, rice as essential crops for growers . It'll helps growers to identify the suitable variety for timely sowing and resistance kinds and further cycles per time can be the product rate in world growers and promotes the income position in growers. But these styles has numerous barriers in adaptations of speed breeding technology indeed though it was introduced in 2018 By NASA. By several factors and [11](Samantara et.al 2022) walls. These barriers where blocked the pathways in adoptation of speed breeding technology among Agriculture scholars, Farmers, agristokeholders and educational institutions and University in Adoptation. Numerous exploration has only done in Lab side only of adoptation of the technology not in the external area where people's can borrow these technology. In my exploration study I've Analysed an crucial walls in adoptation of these technology using an check grounded Research for 30 days in colorful sections like Chengalpettu, villupuram, Namakal and etc. In this sections colorful exploration instructions, kvk, and agrarian instructions and University has been shared in these Research study in these check numerous growers and agristokeholders and factory breeders, Experimenters and scholars where shared for chancing the crucial challenges in adoptation of speed parentage technology through direct check and google form response are used for this research.

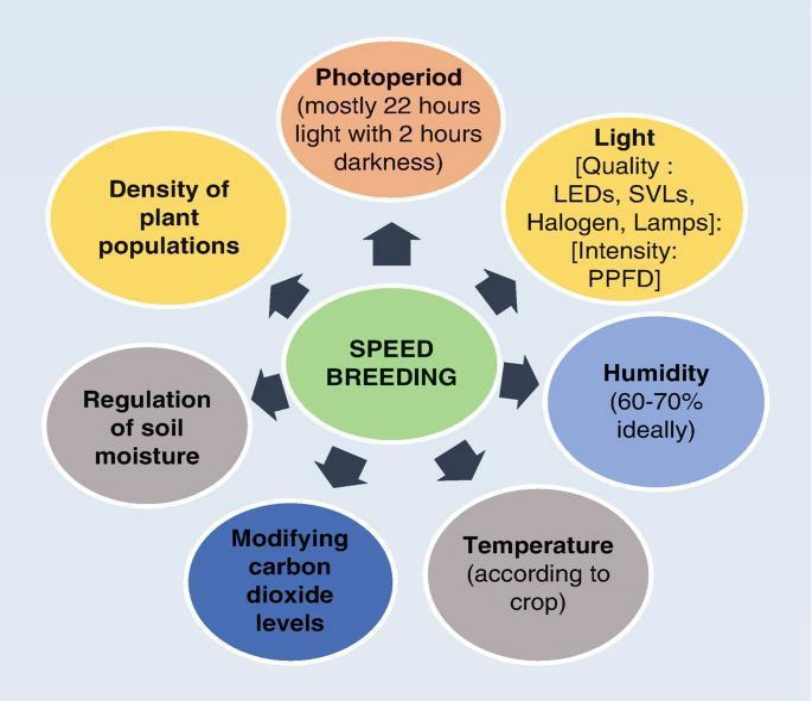

Fig 1. Way involved in speed parentage technology (Rai, N. K et. al 2023)

1.2 Problems statement

At presently lot of arising technologies where introducing each over the world for giving for easy access to people's especially in agrarian field. In this field lot of new technology and chemical and organic way of results is given by numerous agrarian scientists and experimenters every time. From though it was only in the Lab and Not in the Land, growers and agrarian scholars and institutions where not aware of the technologies and method which was introduced in current problems and issues. Numerous barriers and challenges where impact the technology like infrastructure, mindfulness among individualities, restrictions by the agencies are some of important barriers in adoptation of arising new trend technologies [10](Reddy et. **al**) .

1.3 Main objects of the study

The main objects of the exploration study is to breaks the challenges by which they are n't creating the pathway for adoptation of speed breeding technology among growers, agrarian scholars, agristokeholders and setup in the agrarian collages, university and other agrarian institutions. These study was substantially concentrate on giving the right results in current situation and mind- set where it can be attainable recommended to the Agrarian platforms.

II. METHODOLOGY

The method which Used in these study was Survey grounded exploration method with an sample size of 160 samples response which was collected during the 30 days survey period numerous feedbacks, and opinions where sheared by the growers, scholars of agrarian collage, University and other research stations and agri officers as well as extension officers, these check was carried out in 2 ways one is direct check to cultivators and another form of system is through google form for collecting the data from farmers sections and far down people's. This check was conducted in platform in agrarian like scholars, Farmers, Scientists in plant breeding and genetics and Experimenters in this field and professor in agrarian university and agrarian institutions. An by using these sample of 160. I've find an crucial challenges in espousing the technology in agrarian institutions and university by the scholars and professor and other stockholders and etc. in table 1

Table.1: value of no. of participants, category of participants in these speed breeding studies.

Serial no	Participants category	Number of participants	Percentage %
1	Farmers	65	40.63
2	Professor and assistant professor	19	11.88
3	Scientists and plant breeders	10	6.25
4	Students in agri field	56	35.00
5	Extension officer, Ao and agri stockholders	10	6.25

2.1. Research area

These exploration where conducted in sections includes Chengalpettu, Villupuram, Namakal in Tamilnadu states for about 4 weeks The fields includes Agrarian scholars in institutions and university in these sections and growers, agro clinic shop holders, Extension officers, Agrarian officers, Experimenters in kvk and research stations(plant breeders) and scientists in Genetics and plant breeding and Biotechnology departments. In Agrarian institutions(Professor and Assistant Professor) of the Genetics and plant breeding , Seed science and Technology, Extensions and Agricultural Economic departments are substantially concentrated for these study for collection of precious data among these people's for futher analysis.

2.2. Data analysis

The collected data of 160 samples are divided into 2ways direct and google form check to growers and 65 response in direct check to growers and 10 from experimenters and plant breeders, 15 from agrarian stockholders 10 from extension officers, and reaming are 56 response in scholars and 19 from professor in agrarian institutions and university through Google form, these data are analysis by value of total samples and probabilities of actors in the check in groups like(scholars, plant breeders etc). And these can be represented in pie map and Tabular from. These are the data analysis styles followed in the exploration check.

2.3. Research quaternaries

1. Did you ever heard about Speed breeding technology?
2. If Yes means in which crops?
3. what did you know about effective benefits of speed breeding technology?
4. What are challenges or crucial barriers in adoptation of speed breeding technology in real world operation?
5. your opinion on strategies in adoptation of speed breeding technology as arising trends in breeding field?

These are the Research quaternaries which was used in both direct and google form check in these 4 weeks exploration.

III. RESULTS AND DISCUSSION

crucial barriers in adoptation and it's strategies to overcome from the barriers

There are several barriers and challenges are linked in my study and I've only sorted the crucial barriers grounded on the people's opinion and my analysis, I've list out the crucial barriers and their perfecting strategies.

3.1.Awareness level in people's

First and foremost barriers is awareness position in adoptation of new and arising technologies. Day by day lot of new technologies and methods where arrived for perfecting the growers , but people's does not known that technologies due to low mindfulness situations in speed breeding adoptation only15. 6 has apprehensive of this technology rest of 84.6 is not apprehensive in my study. So people's has to ameliorate the aware and understand the current arising technologies in the world. [8,7].

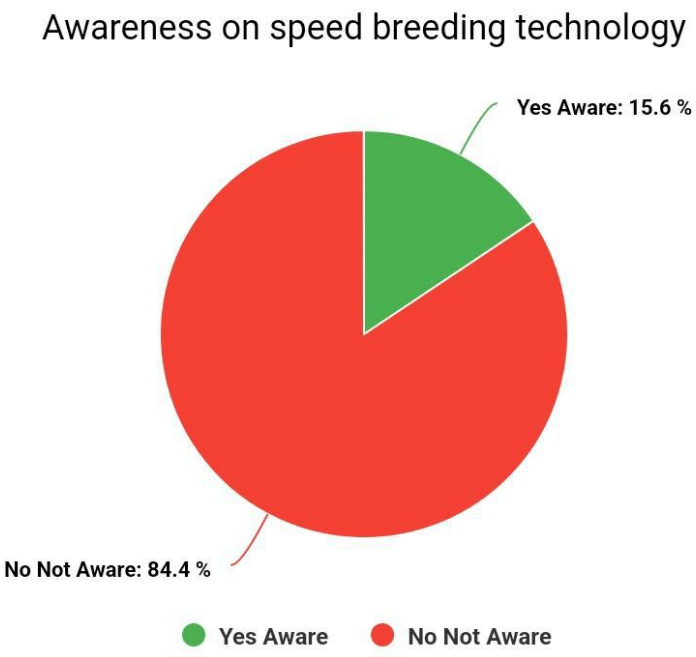

Fig.2:Awarenes level in speed parentage technology

3.2 High cost outfit(Led light, growth chambers etc.)

This technology was only followed only in Lab and not in land so the the cost of outfit is veritably high and regular maintaince is demanded for outfit around 50 % of the barrier is high cost outfit for setups[15](wanga et.al) . So the government has to feeds the new schemes for setting the chamber setup in university and other agrarian institutions or association for installing of speed breeding technology.

3.3.Limited funding for the research or systems

The limited funding [13] (Sharma et.al) for research participations has to increase for further funding has to given by the central government to the research stations, university and NGO for setting speed breeding technology set up in there area or position and starts there's research in speed breeding.

3.4. Lack of professed breeders

further plant breeders has to trained for speed breeding technology to conduct an research and release of kinds as faster for attains an good profitable position to growers [9] (pasala et. Al 2024)

3.5.other Satergies for overcome from the barriers

For scholars should also has to have an knowledge about speed breeding technology as an advanced technology for crop enhancement, so the government from state and central and top ranking institutions and University has to conduct Hand on Training and shops for Agrarian scholars for perfecting their academic as well as practical knowledge in Genetics and plant breeders field [1](Abbdal et al). And for the growers mindfulness lot in every townlets and sections has to conducted on speed breeding technology for understanding of how speed breeding technology has created impact kinds release as faster in short time of period for better yield.

3.6.Benefits of speed breeding technology in crop enhancement

As we knows speed breeding is an advance molecular genetics tool for perfecting the food security in our world, speed breeding has to extensively use for the rapid-fire increase in global population before it attains shortage for food[14] (Watson and Hickey et. al 2021) speed breeding technology release the variety faster, Climate adoptability of crops, creates resistance to biotic and abiotic factors and high genetics effectiveness are the crucial benefits of speed breeding technology are the effective benefits of speed breeding technology . [2]Al-Askar (et.al).

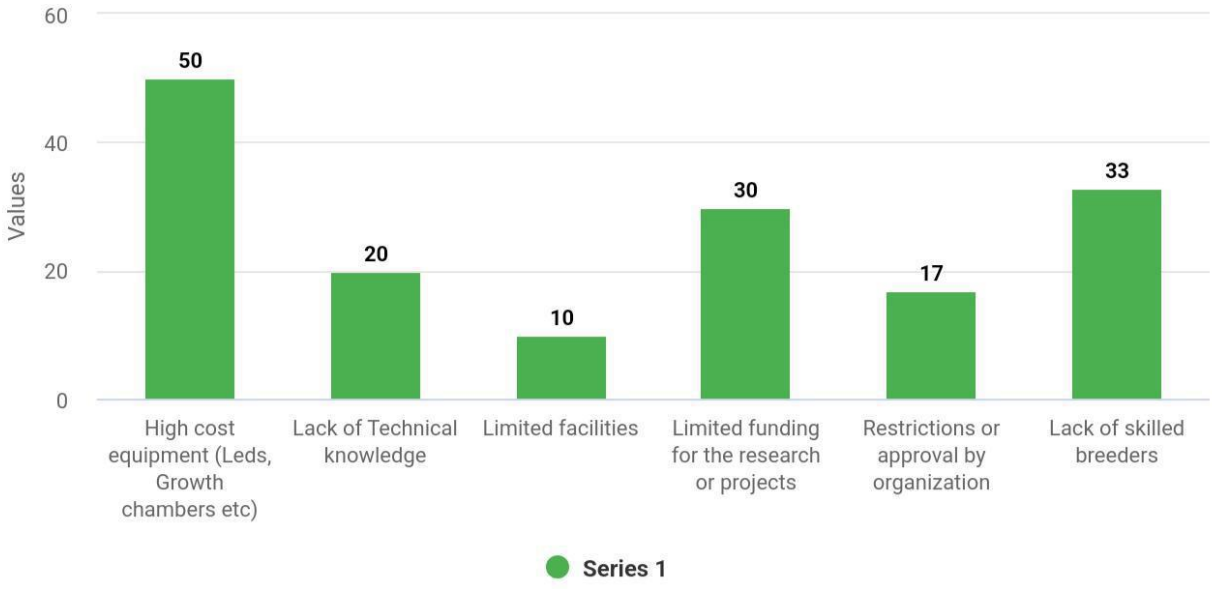

Fig.3.Data analysis on walls on adoptation of speed breeding technology.

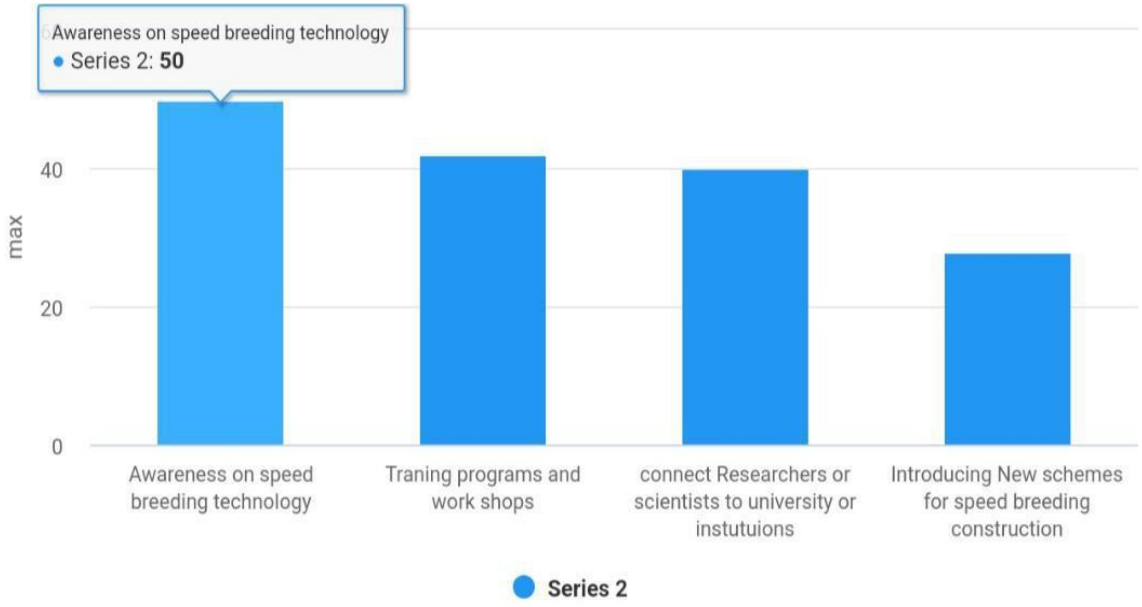

Fig.4:data analysis on strategies in adoptation of speed breeding technology among agrarian field.

IV. CONCLUSION

From the above exploration that we had concluded that the speed breeding is advance molecular tools for accelerating for crop enhancement[6](jighly et al 2019). From these technology we can release further kinds in a short period of time, it has several benefits like rapid release of kinds to growers, climate adoptability, resistance. Indeed though it has further more obstacles for adoptation like Lack of awareness, financial support, restrictions, high cost of outfit for setups and lack of professed breeders are the obstacles faced in adoptation of these technology. From prostrating from these challenges is demands like furnishing hand on training to scholars, awareness camp for growers and furnishing funding for structure setup, Addressing these is pivotal for unleashing the pathway for adoptation for sustainable development in agriculture.

ACKNOWLEDGEMENT

I unfeigned express my thankful to all the professor, assistant Professor, scientists, plant breeders, other agrarian officers, growers and scholars who have shared in the Research check from various agrarian institutions and university. Whose contribute in the exploration and the

companion which motivate these Research to complete and give shaping to the Research and eventually I thank to the all who had support, which was given by our University staffs for completing my Research.

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International Journal of Environment, Agriculture and Biotechnology
Vol-10, Issue-3; May-Jun, 2025
Peer-Reviewed International Journal
Journal Home Page Available: https://ijeab.com/
Journal DOI: 10.22161/ijeab

Rice Breeding for Brown Planthopper Resistance (*Nilaparvata lugens* Stål.)

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Received: 03 Apr 2025; Received in revised form: 01 May 2025; Accepted: 08 May 2025; Available online: 16 May 2025

Abstract**—***Plant breeding is considered one of the prospective strategies for the BPH [Nilaparvata lugens (Stål.)] resistance development under the modernized rice production system. The BPH-resistant novel rice lines were studied via molecular SSR markers, and the BPH effects on grain yield and the agronomic performance of the rice were also reported. The seven rice lines were obtained from the parents OM6683 (donor) x OM6162 (recipient), and two TN1-susceptible and Ptb33-resistant checking cultivars were used through the standard seed box screening technique. The results showed that seven rice lines and the OM6683 variety almost contained the BPH-resistance genes Bph1, Bph3, and Bph13 by utilizing three simple sequence repeat markers, like RM1103 (200 bp), RM204 (200 bp), and RM545 (220 bp). In addition, all of these rice lines/varieties also uncovered the BPH-resistance characteristics from resistant (3, scale) to highly resistant (1, scale) for four diverse BPH populations (Can Tho, Dong Thap, Tien Giang, and Hau Giang provinces) in both Autumn-Summer and Spring-Winter seasons. Furthermore, the results of BPH-resistance characteristics, grain yield, and agronomic traits were better than in the five rice lines G1-BC_2F_5-7-1-1-5-10, G2-BC_2F_5-8-1-1-9-5, G3-BC_2F_5-11-1-1-8-7, G4-BC_2F_5-54-1-1-5-2, and G5-BC_3F_4-8-1-1-1-5 as compared to other rice lines and the parents OM6162 and OM6683. In conclusion, the studies suggested that these potential rice lines can be harnessed as donor pivotal genetic sources to develop BPH-resistant novel rice varieties combined with valid agronomic and quality traits, and high crop yield.*

Keywords**—Rice (Oryza sativa L.), Brown planthopper, BPH resistance genes, MAS (Molecular Marker-Assisted Selection), Plant breeding.**

I. INTRODUCTION

Backcrossing-based plant breeding is mostly through phenotyping selection on the segregation of progeny generations for an excellent rice plant individual. There were advanced endeavors in plant breeding through the phenotyping selection for the key characteristics; however, they generally face constraints during the selection procedure due to the interaction between genotypes and environments. These challenges shall be addressed using molecular markers in plant breeding programs to enhance selection efficiency [1-3]. The MAS (marker-assisted breeding) approaches have diverse benefits because the plant traits cannot be assessed under field conditions [4, 5]. The MAS breeding research has revealed the important roles of genetic diversity determination, the interaction of various crop species, and the sustainability of genetic materials of crop plants [6, 3].

Out of different DNA markers, microsatellites are codominant shall increase the effectiveness and accuracy of the genetic algorithm of population-aided these makers as compared with the other makers, such as AFLP and RAPD; these markers show high allelic diversity; are easily and economically experimented by PCR analysis, and the procedures can be automated and the heterogeneous can be detected clearly during the experiments [7, 8, 4]. Many potential SSR markers have been identified in rice species, and more than 25,000 genes have been known as molecular markers in plants [9-11]. Many molecular marker-based research studies involving different varieties and cultivars have been proposed related to genome mapping, genetic diversity assessment, and marker-based breeding [12, 13, 4]. Plant breeding for BPH-resistance genes in rice varieties with multiple resistant mechanisms helps to give a reliable and broad spectrum of resistance against BPH, and protection and improvement of natural enemies and predators (*Anagrus nilaparvatae*) in the activities' efficiency [14-20, 3, 21] and reducing the application of agrochemicals [22-27]. In contrast, the overuse and misuse of chemicals and fertilizers are associated with unfavorable weather conditions, leading to a changing insect pest quantity and density, damage incidence, and shifting of the BPH biotypes. After that, BPH became more tolerant; further, BPH's damage also transfers an agent as a virus on rice plants [28-33, 27, 34, 35].

Till now, in rice, scientists have categorized the BPH populations into four distinct biotypes [22, 24, 31-33]. In the case of biotype 1, this biotype is a population determined in East and Southeast Asia. The *Bph1* gene was first discovered in the IR26 rice variety from the parents IR24 and TKM6 and displayed resistance against biotype 1 [13]. While biotype 2 is reported as the dominant biotype of the BPH population and originates in Indonesia and Vietnam [36-38, 22, 39, 4, 18, 40, 41] and the *bph2* gene was known in IR36 rice variety and identified resistance to biotype 1 and 2, but this gene is not against biotype 3. The resistance of rice during the impacts of BPH populations and biotype 3 has been known by IRRI [42] and Japan. In the remaining population, biotype 4 appeared only in South Asia countries. Three specific R-genes, *bph5*, *Bph6*, and *bph7*, show resistance against biotype 4, but could not be for biotypes 1, 2, and 3 [23, 30, 32, 39, 41]. In addition, in the Mekong Delta regions of Vietnam, there were several wild rice [43], traditional rice cultivars [39, 44, 45], and many rice lines/varieties (including OM9582, OM9577, OM6976, OM7364, OM6683, etc.) [46-52, 41, 53, 54, 55] showed high resistance to reducing vary BPH populations's damage in various rice cultivation regions of Vietnam. These results also indicated that these resistance rice varieties can have the presence of strong BPH-resistance genes or a BPH-resistance gene pool in rice, therefore, future investigation needs to be executed for the identification of the presence of BPH-resistance genes in these rice varieties *via* MAS [11, 56-66]. To date, 38 resistance genes have been identified on different rice chromosomes *via* BPH resistance analysis on the cultivated *Oryza sativa* and Wild rice species of rice germplasm resources gathered from diverse regions worldwide [67, 68]. Generally, all of the BPH R-genes have extensively been studied in plant breeding programs across Worldwide, especially Asian country's rice tropical cultivation with various BPH's biotypes and virulence in the field, however not three genes *bph5, bph7,* and *bph8*, some other BPH-resistance genes, and QTLs were determined and mapped on different chromosomes and associated with the resistance characteristics to BPH on 7 chromosomes (2, 3, 4, 6, 10, 11, and 12), these chromosomes almost present in *Indica* and wild rice species [69, 6, 70-74, 67, 75, 68, 76]. The results demonstrated that not all known genes show significant functions for resistance to various BPH populations prevalent throughout many Asian countries; many of those genes are effective with tagged molecular markers [77]. Among the determined BPH-resistance genes, *Bph14* (on chr. 3), *Bph3/Bph17* (on chr. 4), *Bph26* (on chr. 12), *bph29* (on chr. 6), *Bph18* (on chr. 12), *Bph6* (on chr. 11), *Bph32* (on chr. 6), and *Bph9* (on chr. 12) have been used for heritable studies *via* the cloning approach [78-81, 67, 82-84]. Out of the BPH-resistance genes that were published, 10 genes were identified at the stage of fine-map comprising *Bph1*, *bph2*, *Bph3*, *Bph9*, *Bph14*, *Bph15*, *Bph18*, *Bph19*, *Bph20*, and *Bph21* [70, 54, 55].

The markers-based selection and breeding are considered prominent approaches for the identification of present BPH-resistance genes in the host plant because of the merits of the molecular markers comprising economics, ease to manipulate, and ubiquitous presence and uniform distribution in the genome due to genetically sources under high-throughput materials data [85-88, 41, 53, 89, 84]. The present study was carried out with the main goal is to identify the BPH-resistance genes that introgression into the back crossing-based generated rice lines from the OM6683 rice variety donor and OM6162 rice variety recipient using the controlled screening methods in the greenhouse and the field with artificial pressure screening by direct inoculation of BPH individuals on seedling rice plants, along with evaluation agronomic traits, yield components, and grain yields; and using the molecular genetic techniques for the reported gene-linked SSR markers-based genotypic assessment for the BPH resistant in rice species. The findings showed that out of the seven potential rice lines, we screened three rice lines

from the OM6162/OM6683//OM6162 hybridization combination, which exhibited high resistance against BPH and received better agronomic performances in comparison to other rice lines and the parent rice varieties. In this report, we named these rice lines G1-BC_2F_5-7-1-1-5-10, G2-BC_2F_5-8-1-1-9-5, G3-BC_2F_5-11-1-1-8-7, G4-BC_2F_5-54-1-1-5-2, and G5-BC_3F_4-8-1-1-1-5, which were used for further evaluation in farmers' fields at different regions and serve for the rice production program of new BPH-resistant rice varieties of the countries.

II. MATERIALS AND METHODS

1. Plant materials

Plants source were from seven rice lines (containing four lines BC_2F_5 and three lines BC_3F_4) of hybridization combination OM6162/OM6683//OM6162, in which OM6162 (recurrent parent) and OM6683 (donor parent) were performed as the primary parents' rice varieties (high-quality rice varieties), and susceptible check variety TN1 (non-carrying resistance gene), and resistance check variety Ptb33 (carrying resistance gene: *bph2*, *Bph3*, and *Zlh3*) [50, 77]. The BPH population sources were collected at four distinctive rice-cultivating regions of the Mekong River Delta of Vietnam, *viz.* Can Tho, Dong Thap, Tien Giang, and Hau Giang provinces.

2. Phenotypic assessment

The plant phenotype of seven rice lines was checked through the BPH damage levels recording to plants based on a standard seed-box screening test (SSST) under greenhouse conditions at a temperature of 28-30^{o}C and RH of 70-80%, the technique was offered by the International Rice Research Institute [90]. The rice seeds were presoaked in clean water for 36 hours and then kept at room temperature for 24 hours in dark conditions for sowing in a plastic/steel tray. After that, the tiny seedlings of seven rice lines were sown in rows of 35 x 25 x 10 cm, along with the donor and recurrent parents, OM6683 and OM6162 varieties, susceptible and resistant checks, TN1 and Ptb33, respectively. A total of 20 seedlings per row were maintained per line. There were three replications for each line, and these seedlings were infested at 7 days old with the 2nd to 3rd instar hopper, 5-8 nymphs per seedling (BPH population samples were collected in a test tube, given in a tray, and counted for the number of BPH per seedling). Seeds of susceptible check TN1 were sown in two border rows and half of the middle row.

After one week to ten days, old seedlings were infested with BPH; after this infestation, the hopper burn 'symptom' was observed and recorded on the rice seedlings. When 100% of the susceptible check TN1 shows wilting and drying symptoms, the plants were scaled individually at growth stage level 2 (for the greenhouse), the evaluation is based on the damage scaling system, and each seedling was scaled as 0 = no injury/damage, 1 = Very slight injury/damage, 3 = first and second leaves of most plants partially yellowing or incompletely all leaf, 5 = Pronounced yellowing and stunting or about 10 to 25% of the plants wilting or dead and remaining plants severely stunted or dying, 7 = More than half of the plant dead, 9 = All plants dead.

3. Genotypic assessment

DNA extraction was done using the mini DNA method 91, 2] described. Leaf samples were collected after phenotypic assessment, *i.e.*, about two weeks after sowing. These leaf samples were taken in the morning as salt concentration inside the leaf is low and the enzyme activity is less; this is the best condition to extract DNA. The quantity and quality of DNA samples were checked using a spectrophotometer and electrophoresis analysis, respectively. These DNA samples were run on an agarose gel (0.9%) in a solution of TAE 1X. The high-purity quality of DNA samples was stored at -20^{o}C.

4. The analysis of SSR markers

The PCR products were amplified using SSR markers following the methods by a Bio-Rad machine. The PCR amplification procedure for SSR markers is suggested and illustrated by [91, 92, 2], Tables 1 and 2.

The SSR products were checked on an agarose gel 3% in a solution of TBE 1X combined with ethidium bromide. Using 7µl of PCR products and 4µl of ethidium bromide solution in each well. Horizontal electrophoresis was used to run PCR products for 1-2 hours, depending on the characteristics of the primer pair. After that, the running of PCR samples was observed on the gel, and the gel was gently taken out to take a photo. The bands appeared on film to find the resistance and susceptible genes based on standard bands of the DNA ladder (50bp and 100bp).

Table 1: The list of primers was used in PCR reactions.

Markers	Primers	Chr.	Linked gene	Ref.
RM1103	Forward 5' CAGCTGCTGCTACTACACCG 3' Reverse 5' CTACTCCACGTCCATGCATG 3'	12	*Bph1*	Park et al. [47]
RM204	Forward 5' GTGACTGACTTGGTCATAGGG 3' Reverse 5' GCTAGCCATGCTCTCGTACC 3'	6	*Bph3*	Jairin et al. [48]
RM545	Forward 5' CAATGGCAGAGACCCAAAAG 3' Reverse 5' CTGGCATGTAACGACAGTGG 3'	3	*Bph13*	Chen et al. [50]

Table 2: PCR solution preparation for each reaction.

Components	Stock solution	Final solution	Volume for each reaction
Duplicated Distilled H_2O	-	-	8,5µl
PCR buffer (10X)	10X	1X	1,5µl
dNTPs	1mM	0,1mM	1,0µl
Forward primer	5µM	0,25µM	0,5µl
Reverse primer	5µM	0,25µM	0,5µl
Taq polymerase	0,75U/µl	0,75U/10µl	1,0µl
DNA sample	30ng/µl	60ng/15µl/reaction	2,0µl
Total volume			15µl

Reference: IRRI

5. The field trial of the rice lines was conducted through a BPH-resistance gene pool

The rice lines from prior studies were used for this study through various elaborate analyses. The field's experiments were conducted at Cuu Long Delta Rice Research Institute (CLRRI), Can Tho city, Vietnam. The trials were designed in Randomized Complete Block Design (RCBD) with 3 replications [93] and MARD, 2011 (Vietnamese Standards, QCVN 01-55:2011/BNNPTNT) [94] - the area of a plot at 30m^2/treatment/rep. The distance between plots is 30cm, and between the replications is 40cm.

The specialized technical procedure: The rice seeds were sown on the tray, and the seedlings at 10-12 days old were transplanted into the field as seedlings after sowing. The transplanting density was one plant/hole. The transplanting distance was 15cm x 20cm spacing, around 33 plants/m^2. Fertilizer application 100N-40P_2O_5-30K_2O kg/ha in the Spring-Winter season.

The insect pests were investigated according to Vietnamese Standards (MARD, 2011) (QCVN 01-38: 2010/BNNPTNT, 2010) [94]. The evaluation of insect pest resistance in the field on the potential rice lines was performed following the SES (Standard Evaluation System) for rice [90]. The BPH (*Nilapavata lugens* Stål.) was evaluated by the different levels at the growth stage (3-9): 0-scale: No injury; 1-scale: Slight yellowing of a few plants; 3-scale: Leaves partially yellow but with no hopper burn; 5-scale: Leaves with pronounced yellowing and stunting or wilting and 10-25% of plants with hopper burn, remaining plants harshly stunted; 7-scale: More than half the plants wilting or with hopper burn, remaining plants harshly stunted; 9-scale: All plants dead. Culm strength and plant type were evaluated at the different levels: Culm strength: 1-scale: Strong (no bending); 3-scale: Moderate strong (most plants bending); 5-scale: Intermediate (moderately bending of most plants); 7-scale: Weak (nearly flat of most plants); 9-scale: Very weak (all

plants flat). Plant type: 1-scale: Simply; 2-scale: Intermediate; 3-scale: Open.

Evaluation and recording of the parameters' data of growth, development, and grain yield according to National Technical Regulation on Testing for Value of Cultivation and Use of Rice varieties - VCU (Vietnamese Standards, QCVN 01-55: 2011/BNNPTNT) (MARD, 2011) [94]. The potential rice lines were evaluated for agronomic traits, yield parameters, and grain yield. The growth period (85% of grain per panicle): the trait was recorded from the sowing date to the ripening panicle stage, > 95%. Plant height (cm): measure from the surface of the soil near the stalk to the top of the tallest panicle (awns excluded). Number of filled grain/spike (grain): Count all filled grain/spike of 10 tillers and calculate the average of 3 replications. 1,000 grains weight (gram): Weigh 1,000 grains at 14% moisture content, with 3 replications. Grain yield (ha^{-1}): Weigh the harvested grains' weight with 5 square meters at 14% moisture content, with 3 replications.

III. RESULTS AND DISCUSSION

1. Development of rice line populations based on phenotypic evaluation combined with molecular markers

The presence of BPH-resistant genes in rice lines was identified as follows. The rice lines populations in the F_1, BC_1F_1, BC_2F_1, BC_2F_2, BC_3F_1, and BC_3F_2 were evaluated on both genotypes and phenotypes. Rice lines were selected in the F_1, BC_1, BC_2, and BC_3 generations with heterozygous resistance genotypes in all 3 markers to continue backcrossing in the next generation. Rice lines were selected in the BC_2F_2 and BC_3F_2 generations with homozygous resistance genes in 3 resistance genes and self-pollinated to select pure lines in the next generation.

The backcrossing results of the combination OM6162/OM6683//OM6162 were summarized in Fig. 1 and Table 3. The number of individuals carrying the BPH resistance gene was selected through molecular markers combined with phenotypic evaluation in the F_1 (117), BC_1 (14), BC_2 (6), and BC_3 (9) generations of the combination OM6162/OM6683//OM6162 (Table 3). As the previous study has been published by [54, 55], the similarity results on the rice lines have high resistance to diverse BPH populations, but not on the donor variety OM6683.

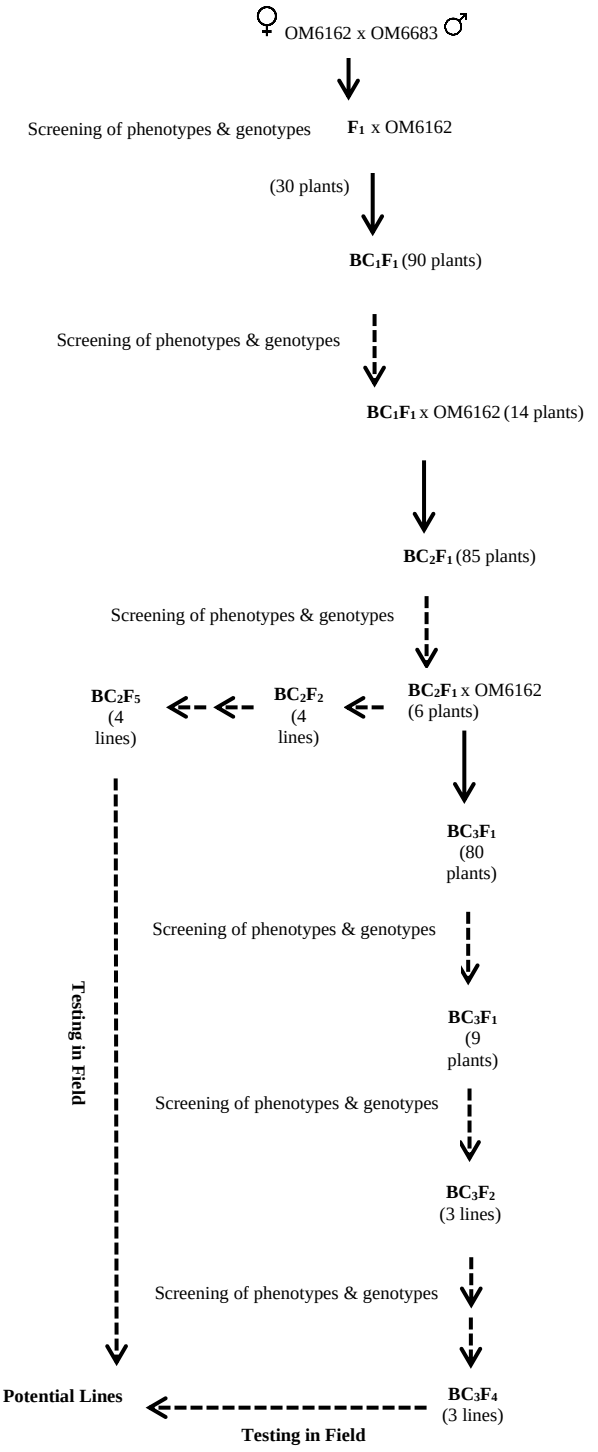

Fig.0. Scheme of hybridization and breeding of the OM6162/OM6683//OM6162 combination for BPH resistance rice lines

Table 3. The number of BC rice lines from the two combinations OM6162/OM6683//OM6162.

Generations	Total of rice lines	Number of selected rice lines *via* genotypes and phenotypes screening
F_1	180	117
BC_1F_1	90	14
BC_2F_1	85	6
BC_3F_1	80	9

+ F_1 generation: 30 rice lines were bred included of I-1; I-2; I-4; I-6; I-7; I-8; I-9; I-10; I-11; I-13; I-14; I-18; I-19; I-20; I-25; I-28; I-30; I-32; I-33; I-35; I-40; I-41; I-42; I-45; I-46; I-47; I-53; I-54; I-52; and I-56.

+ BC_1F_1 generation: 14 rice lines were bred included of I-6-1; I-7-1; I-8-1; I-9-2; I-10-2; I-11-1; I-14-2; I-19-1; I-47-1; I-53-3; I-53-4; I-54-1; I-52-1; and I-56-2.

+ BC_2F_1 generation: 6 rice lines were bred included of I-7-1-1; I-8-1-1; I-11-1-1; I-17-1-2; I-53-4-1; and I-54-1-1.

+ BC_3F_1 generation: 9 rice lines were bred included of I-7-1-1-1; I-7-1-1-2; I-7-1-1-3; I-8-1-1-1; I-11-1-1-1; I-17-1-2-1; I-53-4-1-1; I-54-1-1-1; and I-54-1-1-2.

1.1. Breeding of BPH-resistant rice lines in the field

Rice lines of the BC_2F_2, BC_2F_3, BC_2F_4, BC_3F_2, and BC_3F_3 populations were planted in experimental fields to breed pure lines resistant to brown planthoppers.

Table 4. The BPH resistance rice lines in the field were bred from the OM6162/OM6683//OM6162 combination.

Season	Generation	Total rice lines	Rice lines bred	Individuals bred
Autumn-Summer 2016	BC_2F_2	63	4	30
Spring-Winter 2016-2017	BC_2F_3	30	17	25
	BC_3F_2	45	3	20
Autumn-Summer 2017	BC_2F_4	25	10	4 (promising lines)
	BC_3F_3	20	7	3 (promising lines)

Rice lines carrying brown planthopper resistance genes were bred, as well as these lines posing good agronomic characteristics that were evaluated according to standards released by IRRI (2013), of plant hardness, shape, growth period, resistance to major pests and diseases, out of which most importantly are the yield of promising lines. The results of breeding BPH-resistant rice lines in the field of two combinations, OM6162/OM6683//OM6162 illustrated in Table 4. In other studies, the authors also reported the good agronomic components and high yield on the potential rice lines carrying the BPH resistance genes when those rice lines were trialed in the field [54, 55].

1.2. Genotype's assessment of the rice line population

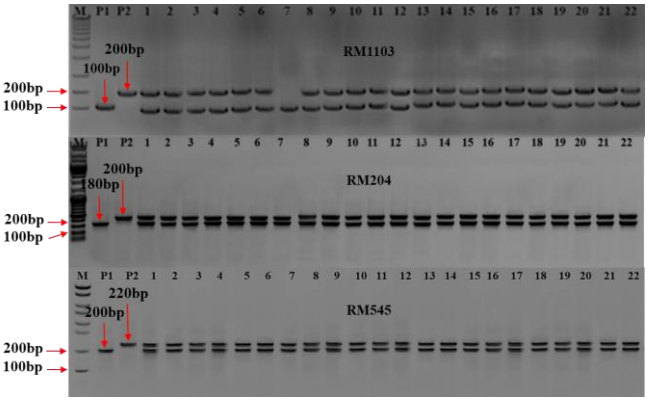

Fig.1: F_1 generation's genotypes of the OM6162/OM6683 combination were evaluated using markers *RM1103, RM204, and RM545. P1: OM6162, P2 OM6683; 1-22: F_1 hybrid lines population, M: Ladder 100bp*

In these results, based on phenotyping combined with genotyping, the authors bred 04 and 03 elite and potential rice lines at BC_2F_4 and BC_3F_3, respectively, which carry 03 codominant resistant genes (*Bph1*, *Bph3*, and *Bph13*). After that, those rice lines were self-pollinated to breed pure rice lines in the future generation (assessment results were illustrated in Fig. 1 to Fig. 8). Many researches have been used three markers RM1103, RM204, RM545 to determine the presence of three genes *Bph1*, *Bph3*, *Bph13* in rice, *Bph1* gene. For the *Bph1* gene idemtifed in some rice varieties such as Mudgo [95, 96, 66], IR747B-6 and IR28 (TKM6) [97-99], Vietnamese's rice varieties: OM6683, OM5954, OM7364, TLR493, and Tau Huong [54], *Japonica* rice varieties [100], Norin-PL3 rice variety [101]. For the *Bph3* gene known in Ptb33, Rathu Heenati [102, 103, 77]. For the *Bph13* gene explored in several rice varieties: OM6683, OM5954, and OM7364, Tau Huong, *O. officinalis* [104, 54], IR54745-2-21-12-17-6 rice variety, and *O. officinalis* wild rice [105], wild rice *Oryza eichingeri* [106].

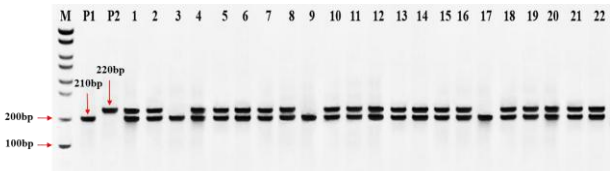

Fig.2: BC_1 generation's genotypes of OM6162*2/OM6683 combination were evaluated using marker *RM545. P1: OM6162, P2 OM6683; 1-22: BC_1 hybrid lines population, M: Ladder 100bp*

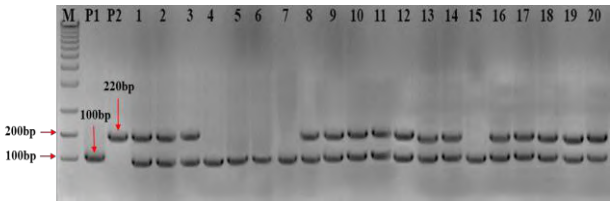

Fig.3: BC_2 generation's genotypes of OM6162*3/OM6683 combination were evaluated using marker *RM1103. P1: OM6162, P2 OM6683; 1-22: BC_2 hybrid lines population, M: Ladder 100bp*

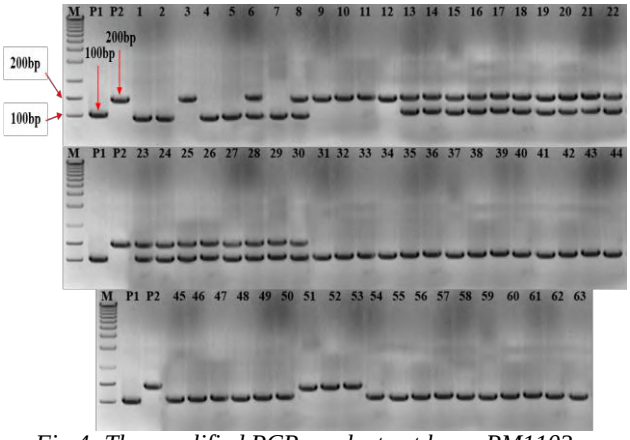

Fig.4: The amplified PCR products at locus RM1103 on chromosome 12 of BC_2F_2 rice lines of OM6162*2/OM6683 combination. *P1: OM6162, P2 OM6683; 1-63: BC_2F_2 hybrid lines population, M: Ladder 100bp*

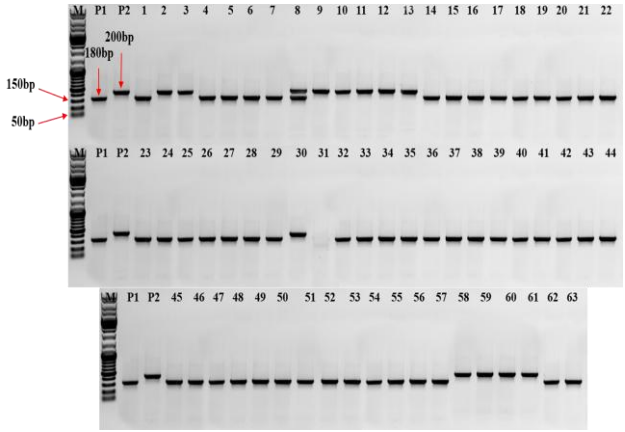

Fig.5: The amplified PCR products at locus RM204 on chromosome 6 of BC_2F_2 rice lines of OM6162*3/OM6683 combination. *P1: OM6162, P2 OM6683; 1-63: BC_2F_2 hybrid lines population, M: Ladder 50bp*

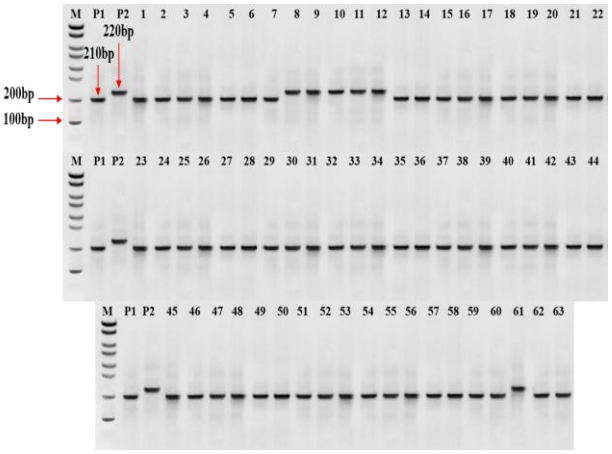

Fig.6: The amplified PCR products at locus RM545 on chromosome 3 of BC_2F_2 rice lines of OM6162*3/OM6683 combination. *P1: OM6162, P2 OM6683; 1-63: BC_2F_2 hybrid lines population, M: Ladder 100bp*

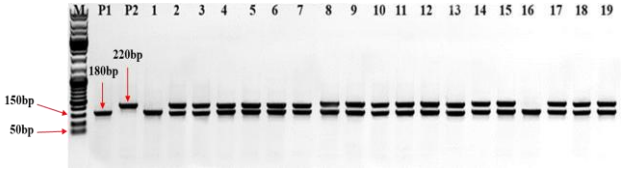

Fig.7: BC_3 generation's genotypes of OM6162*4/OM6683 combination were evaluated using marker *RM1204. P1: OM6162, P2 OM6683; 1-19: BC_3 hybrid lines population, M: Ladder 50bp*

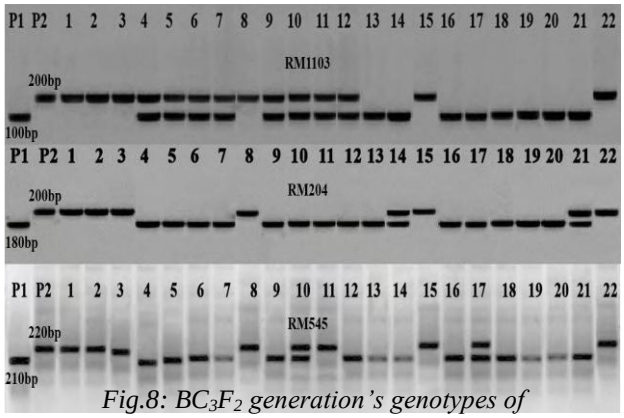

Fig.8: BC_3F_2 generation's genotypes of OM6162*4/OM6683 combination were evaluated using markers *RM1103, RM204, and RM545. P1: OM6162, P2 OM6683; 1-22: BC_3F_2 hybrid lines population, M: Ladder 100b*

2. The elite and potential rice lines for BPH-resistance

2.1. The presence of *Bph1, Bph3, and Bph13* genes for BPH-resistance in seven rice lines

The genes were for resistance to BPH from the genetic background of the backcrossing-based bred rice lines of the donor sources, the OM6683 rice variety, using the marker-assisted selection as shown in Table 5 and Fig. 9. The genotype screening assessment was performed using resistance gene-linked markers to evaluate resistance to BPH in each rice line (Fig. 9). The results of the current study showed that all seven potential rice lines had the presence of all three BPH-resistance genes *Bph1*, *Bph3*, and *Bph13 via* various resistance gene-linked SSR markers, including RM1103 (Fig. 9a), RM204 (Fig. 9b), and RM545 (Fig. 9c), respectively. For the primer RM1103, the *Bph1* gene was detected at 200bp on seven rice lines and cultivar OM6683 (P2) as compared to cultivar OM6162 (P1) (susceptible variety, at 100bp) (Fig. 9a). In the case of the primer RM204, the expression of the *Bph3* gene was determined in all the varieties and located at 200bp under this investigation, except the OM6162 cultivar at 180bp (Fig. 9b). The primer RM545 was as the results in "Fig. 9b" revealed that the *Bph13* gene was identified at a position of 220bp in cultivar OM6683 (P2), as well as seven rice lines were coded into 1-7, however this location did not detect in OM6162 cultivar, instead of that is at 210bp position. As part of this result (part 1) described above, the crucial role of three genes during the exposure of rice plants to the damage of BPH populations through stimulating the response and/or resistance characteristics. Our understanding was investigated based on the studies on phenotyping and genotyping assessment in the greenhouse and the field for BPH resistance of rice *via* the activation of the BPH resistance genes group, *viz. Bph1*, *Bph3*, and *Bph13* [54, 55, 107].

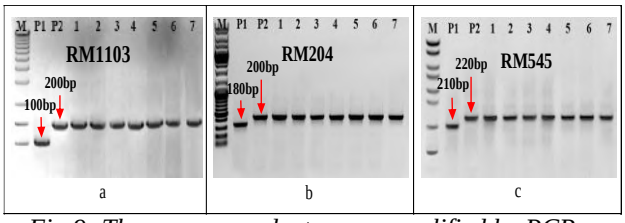

Fig.9: Three gene products were amplified by PCR on agarose gel (3%) using 03 MM: RM1103 (Bph1), RM204 (Bph3), RM545 (Bph13) for 07 rice lines of the OM6162/OM6683 combination. *P1: OM6162, P2 OM6683; 1-63: BC_2F_2 hybrid lines population, M: Ladder 50bp and 100bp*

2.2. The BPH-resistance characteristics of seven rice lines in a greenhouse through seed-box methods

The rice plant's resistance/susceptible characteristics to BPH of the potential rice lines (these lines were the products of backcrossing-based hybridization of the recipient (OM6162) and donor (OM6683) parents were evaluated on 4 brown plant hoppers populations, which have been collected in 4 provinces such as Can Tho, Dong Thap, Tien Giang, and Hau Giang, as well as the controlling varieties were TN1 (susceptible check) and Ptb33 (resistant check) were also harnessed to assess the responses of rice varieties to the BPH's damages, as the results were shown in Table 5. Those potential rice lines were found to be the resistance (R) reactions with 4 BPH populations at a damage scale range from 1-3 (resistant - R), including OM6683 rice variety (3, scale - resistant), these results were comparable to TN1 (susceptible control) variety at a scale of 9 (highly susceptible) and Ptb33 was at a scale of 3 (resistant control) (Table 5). Among 4 BPH populations, only Hau Giang's population exhibited low damage levels on seven rice lines and the Ptb33 rice variety; these results compared to the other three populations in both seasons (Autumn-Summer and Spring-Winter) (Table 5). Many studies show that the resistance characteristics of multiple genes to damage from insect pests in plants are the most effective and sustainable approaches. Especially, in brown planthopper populations, many pyramided genes were in rice plants showing higher resistance levels compared to a single gene in a particular rice variety/cultivar during the effects of diverse BPH biotypes [108, 109, 54, 55]. Multiple resistance genes present in different rice varieties/cultivars such as three genes *Bph3*, *Bph17*, and *Zlh1* in Rathu Heenati, four genes *bph2*, *Bph3*, *Bph32*, and *Zlh3* in Ptb33 [78, 103, 77]; two genes *Bph6* and *Bph12* in progeny rice lines [110]; two genes *Bph14* and *Bph15* in backcross progeny rice lines; four genes in *Bph1*, *bph4*, *Bph13*, and *Bph17* in Vietnamese's rice varieties/cultivars [111, 54, 55], family R gene - *Bph33(t)* in RIL rice lines - RP2068-18-3-5 (RP2068) (TN1 x RP2068) [112]; three *BPH4*, *BPH9*, and *BPH32* in NIL rice lines [76]; two genes *Qbph6* and *Qbph12* in Khao Dak Mali 105 [113].

Table 5. The BPH-resistance characteristics of the potential rice lines in the Summer-Autumn 2017 and Spring-Winter 2017-2018 seasons (the greenhouse).

S /N	Lines/ varieties	The damage scale of BPH populations on the rice lines (for the greenhouse test)							
		Can Tho		Dong Thap		Tien Giang		Hau Giang	
		AS 2017	SW 2018	AS 2017	SW 2018	AS 2017	SW 2018	AS 2017	SW 2018
1	G1-BC_2F_5-7-1-1-5-10	1	1	3	3	3	3	1	1
2	G2-BC_2F_5-8-1-1-9-5	3	3	3	3	3	3	3	3
3	G3-BC_2F_5-11-1-1-8-7	3	3	3	3	3	3	3	3
4	G4-BC_2F_5-54-1-1-5-2	3	3	3	3	3	3	3	3
5	G5-BC_3F_4-8-1-1-1-5	3	3	3	3	3	3	3	3
6	G6-BC_3F_4-53-4-1-1-1	3	3	3	3	3	3	3	3
7	G7-BC_3F_4-54-1-1-1-2	3	3	3	3	3	3	3	3
8	OM6162	7	7	7	7	7	7	5	5
9	OM6683	3	3	3	3	3	3	3	3
10	TN1	9	9	9	9	9	9	9	9
11	Ptb33	3	3	3	3	3	3	1	1

Annotated: AS: Autumn-Summer; SW: Spring-Winter 2018 (2017-2018). Damage scale and the responses of the rice lines/varieties: 1-3: Resistant (R); 5: Moderate Susceptible (MS); 7: Susceptible (S); 9: Highly Susceptible (HS).

3. The BPH resistance gene pool of rice lines in the field trial

To evaluate the host-plant resistance against other pests and diseases, field trial research was implemented in the Spring-Winter 2017-2018 season to validate the effectiveness of resistance genes in rice. The results of this present exploration exhibited that the set of seven rice lines and the parents' cultivar OM6683 were highly resistant (scale, 1) or resistant (scale, 3) for 5 insect pests and blast blight diseases, remaining the line G5-BC_3F_4-8-1-1-1-5 unveiled a moderate response (scale, 5) for leaf folder, similarly, the parent line OM6162 showed a medium response level (scale, 5) to planthopper and leaf folder (as illustrated in Table 5). The medium damage level of Blast blight, Thrips, and Planthopper was lower than Leaf folder and Gall midge on seven rice lines and OM6683, except for the OM6162 rice variety. Hence, the results of the present study indicated that seven rice lines are capable of carrying distinct R-genes for different resistance against insect pests such as Thrips, Leaf folder, Gall midge, and pathogen of Blast blight, rather than BPH resistance genes only for brown planthoppers (*Nilaparvata lugens* Stål.). Compare to the previous reports, the results of the present study showed moderate resistance to high resistance for mainly five insect pests (BPH, Thrips, Leaf folder, Gall midge, Blast blight) in rice plants, these results were also similar to former studies have been published in rice, like BPH [114, 115], BPH, Thrips, Leaf folder, and Gall midge [114, 116-119], BPH [120], Gall midge resistance [121], Blast disease [122-125].

Table 6. The resistance characteristics of the potential rice lines against some insect pests and diseases, Spring-Winter 2017-2018 season (the field).

S/N	Lines/ varieties	BPH (scale 0-9)	Thrips (scale 1-9)	Leaf folder (scale 0-9)	Gall midge (scale 0-9)	Blast blight (scale 0-9)
1	G1-BC_2F_5-7-1-1-5-10	1	1	3	3	3
2	G2-BC_2F_5-8-1-1-9-5	1	1	3	3	1
3	G3-BC_2F_5-11-1-1-8-7	1	1	3	3	1
4	G4-BC_2F_5-54-1-1-5-2	1	1	3	3	1

5	G5-BC_3F_4-8-1-1-1-5	1	1	5	3	1
6	G6-BC_3F_4-53-4-1-1-1	1	1	3	3	1
	G7-BC_3F_4-54-1-1-1-2	1	1	3	3	1
7	OM6162	5	3	5	3	3
	OM6683	1	1	3	3	1

Annotated: Damage scale and the responses of the rice lines/varieties: 1-3: Resistant (R); 5: Moderately Susceptible (MS); 7: Susceptible (S); 9: Highly Susceptible (HS).

3.1. The growth characteristics, yield components, and yield of the potential rice lines

The outcomes of the present study showed off that the seven rice lines and parents rice varieties OM6162 and OM6162 possessed a growth period distinguishing from 95-102 days, of which three rice lines < 100 days of the growth period containing lines like G2-BC_2F_5-8-1-1-9-5, G3-BC_2F_5-11-1-1-8-7, and G4-BC_2F_5-54-1-1-5-2, the rest lines were ≥ 100 days of the growth period. The plant height average of seven rice lines was low from 93.7-110.3 cm, among these three lines G4-BC_2F_5-54-1-1-5-2 (98.3 cm), G5-BC_3F_4-8-1-1-1-5 (93.7 cm), and G7-BC_3F_4-54-1-1-1-2 (96.7 cm) and one rice variety OM6683 (99.0 cm) retained plant height < 100 cm, whereas the rest of other lines and OM6162 rice variety had taller plant height > 100 cm. In case the number of panicles per hill was from 8.0-10.7 panicles, and the panicle length was from 22.2-24.2 cm, and virtually no non-significant difference between those lines and the parent's rice varieties, especially these three rice lines. In addition, the culm strength of rice lines uncovered at 3, scale *i.e.*, moderately strong (most plants bending) to scale 1, *i.e,*. strong level [90], and the plant type was from the moderate compact type (Table 6). Furthermore, all seven rice lines showed higher rice yield and significant differences at the P = 0.05 level compared to the OM6162 cultivar, because this cultivar was damaged by the BPH effects, inducing lower grain yield and other performance traits, as illustrated in Table 7. Among seven rice lines, five rice lines revealed higher grain yield with significant differences at the P = 0.05 level as compared to the parents' rice varieties as well as other rice lines, these lines were G1-BC_2F_5-7-1-1-5-10, G2-BC_2F_5-8-1-1-9-5, G3-BC_2F_5-11-1-1-8-7, G4-BC_2F_5-54-1-1-5-2, and G5-BC_3F_4-8-1-1-1-5; among of which, the line G4-BC_2F_5-54-1-1-5-2 impressively showed on the highest grain yield at 7.7 tons/hectare. Similarly, in the case of other traits' performance, *viz.*, a quantity of filled grain/panicle, flat grain percentage, and weight of 1.000 grains, were shown almost higher in these five rice lines as compared to other rice lines and the parents' rice varieties (Table 7, Fig. 10, 11). Overall, the increasing agronomic performance in seven rice lines in comparison to the donor OM6683 and recipient OM6162 rice varieties proved that the BPH-R genes had no yield penalty in the BPH resistance genes-carrying rice lines, these obtained findings might caused by the stimulating of genes expression inherited from the donor genomes, especially, five rice lines mentioned above part. These views again stated the effectiveness of the MAB and MAS programs in transferring R-genes into elite rice varieties and simultaneously obtaining the identical target genes for insect pest resistance. As compared to previous studies that reported, we may desmonstrate that the potential molecular events and resistance mechanisms based on the interaction between host-plant-insect pests and the central role of R-genes appear inside plant cells, in which the R-genes are activated under the impacts of BPH, helping plants survive, maintain the growth and development, promote and enhance yield components and high yield of rice plants. These BPH-resistant mechanisms resulted from the phenotyping and genotyping assessment by the participation of different reactions and mechanisms comprising the specific resistance mechanisms from the host-plant resistance [126], high-regulation of the BPH-resistance genes (including *Bph* and/or *bph* gene type) [127, 112, 54, 55, 107].

Table 7. The growth characteristics of the potential rice lines in the Spring-Winter season 2017-2018.

S /N	Lines/ varieties	Growth period (days)	Plant height (cm)	Culm strength (scale)	Plant type (scale)
1	G1-BC_2F_5-7-1-1-5-10	102	110,3a	1	1
2	G2-BC_2F_5-8-1-1-9-5	98	101,7cd	3	1
3	G3-BC_2F_5-11-1-1-8-7	95	106,7ab	3	1
4	G4-BC_2F_5-54-1-1-5-2	98	98,3de	1	1

5	G5-BC_3F_4-8-1-1-1-5	100	93,7f	1	1
6	G6-BC_3F_4-53-4-1-1-1	102	103,3bc	1	1
7	G7-BC_3F_4-54-1-1-1-2	100	96,7ef	3	1
8	OM6162	102	101,7cd	3	2
9	OM6683	100	99,0cde	1	1
	CV%		2,5		

Annotated: The values of the same column followed by the same letters indicate the statistically non-significant difference under the Duncan test at a 5% level.

Table 8. The agronomical traits and grain yield of the potential rice lines in the Spring-Winter season 2017-2018.

S/N	Lines/ varieties	No. of panicles/ hill (grains)	Panicle length (cm)	No. of filled grain/ panicle (grains)	Flat grains ratio (%)	1.000 grains weight (gr)	Yield (tons/ hectare)
1	G1-BC_2F_5-7-1-1-5-10	8,3bc	22,5b	114,0bc	20,9bcd	26,9ab	7,0b
2	G2-BC_2F_5-8-1-1-9-5	9,7ab	22,3b	124,3ab	17,9cd	27,3ab	7,4ab
3	G3-BC_2F_5-11-1-1-8-7	9,7ab	22,7b	110,0c	22,6bcd	27,1ab	6,8b
4	G4-BC_2F_5-54-1-1-5-2	10,7a	23,3ab	134,7a	15,7d	27,8a	7,7a
5	G5-BC_3F_4-8-1-1-1-5	10,7a	24,2ab	127,7a	17,8cd	27,2ab	7,3ab
6	G6-BC_3F_4-53-4-1-1-1	9,0bc	22,2b	108,3c	24,8ab	26,3b	6,2c
7	G7-BC_3F_4-54-1-1-1-2	8,0c	23,2b	105,3c	27,2ab	26,3b	6,0c
8	OM6162	6,0d	23,7ab	92,7d	30,5a	26,3b	5,2 d
9	OM6683	9,3abc	25,3a	104,7c	26,2ab	27,1ab	6,2c
	CV%	9,3	4,7	5,9	16,3	2,00	4,8

Annotated: The values of the same column followed by the same letters indicate the statistically non-significant difference under the Duncan test at a 5% level.

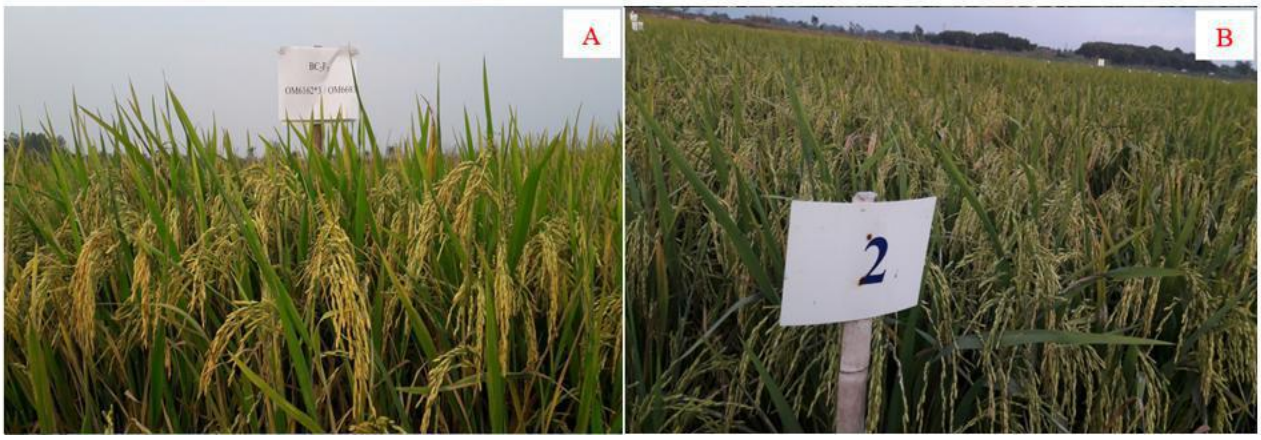

Fig.10: Field trial of promising BPH-resistance rice lines at CLRRI in Spring-Winter 2017-2018

A: Rice line G4-BC2F5-54-1-1-5-2 of OM6162/OM6683//OM6162 combination

B: Rice line G2-BC_2F_5-8-1-1-9-5 of OM6162/OM6683//OM6162 combination

Fig.11: Hybridization rice lines (surviving after resistant assessment) were planted under artificial screening in a net-house

IV. CONCLUSION

In summary, the research breeding three potential rice lines from seven introgression rice lines of the backcrossing population of OM6162/OM6683//OM6162 combination, these rice lines were G1-BC_2F_5-7-1-1-5-10, G2-BC_2F_5-8-1-1-9-5, G3-BC_2F_5-11-1-1-8-7, G4-BC_2F_5-54-1-1-5-2, and G5-BC_3F_4-8-1-1-1-5, which carry three pyramiding BPH-resistance genes *viz. Bph1* (RM1103; 200 bp), *Bph3* (RM204; 200 bp), and *Bph13* (RM545; 220 bp). Furthermore, three rice lines showed BPH resistance levels from resistant (scale 3) to highly resistant (scale 1) through the standard seedbox screening technique (SSST) for four BPH populations at four areas: Can Tho, Dong Thap, Tien Giang, and Hau Giang. Addition, three rice lines out of seven rice lines almost showing the medium damage level of Blast blight, Thrips, and Planthopper (grade 1-3), Leaf folder and Gall midge (grade 3-5), this result indicate that three genes carrying the intergration of resistance to various insect pests under the controlling conditions. Moreover, the yield components and yield of the potential rice lines also show higher levels than before the sources of varieties. In conclusion, the potential rice lines obtained from this study can be used as significant genetic materials for future studies of the breeding programme. These lines need to be studied in a deepening knowledge to understand the molecular biology of the differentially expressed BPH resistance genes and strategies for plants' response and control based on the genomic sequencing integration and the OMICs approaches (genomics, transcriptomics, proteomics, metabolomics, phenomics, ionmics). The key connection of these results is that these potential rice lines must be developed in the main rice production regions to provide novel insect-pest-resistant rice variety sources for the farmers' rice cultivation and sustainable development in the Mekong Delta of Vietnam.

ACKNOWLEDGEMENTS

The author would like to thank Prof. Dr. Nguyen Thi Lang for her help and valuable advice during the study. The author wants to thank Dr. Tran Ngoc He for his support in the manuscript preparation and submission. No conflict of interest declared.

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International Journal of Environment, Agriculture and Biotechnology
Vol-10, Issue-3; May-Jun, 2025
Peer-Reviewed International Journal
Journal Home Page Available: https://ijeab.com/
Journal DOI: 10.22161/ijeab

Effect of Nitrogen Sources and Plant Spacing on Morphological Traits of Kalmegh (*Andrographis paniculata* Nees) under Malwa Agro-Climatic Conditions of Madhya Pradesh

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Received: 07 Apr 2025; Received in revised form: 04 May 2025; Accepted: 11 May 2025; Available online: 17 May 2025

Abstract— *The field experiment trial titled "Effect of nitrogen sources and plant geometry on herbage yield and nutrient uptake in Kalmegh (Andrographis paniculata Nees.)" under Malwa Plateau of Madhya Pradesh" was carried out in at Herbal Garden Department of Plantation, Spices, Medicinal and Aromatic Crops, KNK College of Horticulture, Mandsaur (M.P.) during the Kharif season 2024-25. The experimental Observations on morphological parameters were recorded using standard methods. The study assessed key morphological parameters, including plant height (cm), number of leaves per plant, and number of branches per plant. Observations were recorded from five randomly selected plants at intervals of 30, 60, 90, and 120 days after transplanting (DAT), as well as at harvest. The results indicated that the nitrogen treatment N_1 (40 kg N applied through vermicompost combined with 40 kg N through urea) resulted in the highest values for plant height, number of branches, and number of leaves. Among the spacing treatments, S_1 (20 × 10 cm) was found to be the most effective, also producing the maximum plant height, number of branches, and number of leaves. Furthermore, the combined treatment of $S_1 \times N_1$ consistently recorded the highest values for all morphological traits across all growth stages, including 30, 60, 90 DAT, and at harvest.*

Keywords— ***Kalmegh, nitrogen sources, plant geometry, herbage yield, nutrient uptake.***

I. INTRODUCTION

Kalmegh (*Andrographis paniculata* Nees.), commonly known as the "King of Bitters," is a medicinal herb belonging to the Acanthaceae family. Native to South Asia, particularly India and Sri Lanka, it is now cultivated in various tropical regions worldwide. Kalmegh has been utilized in traditional medicine systems such as Ayurveda, Siddha, and Chinese medicine for centuries. Its applications include treating fevers, liver disorders, respiratory infections, and digestive issues (Shende *et al*., 2025). The plant's therapeutic properties are attributed to its rich phytochemical profile, notably andrographolide, a diterpenoid lactone. Other bioactive compounds include flavonoids (quercetin, kaempferol), polyphenols, steroidal saponins, tannins, and alkaloids, contributing to its antioxidant, anti-inflammatory, and antidiabetic effects. (Banerjee *et al*., 2021). Kalmegh exhibits a broad spectrum of pharmacological activities: Andrographolide enhances insulin secretion, improves glucose tolerance, and exhibits anti-inflammatory and antioxidant activities, contributing to blood glucose regulation. Antiviral and Immunomodulatory Properties: Studies have shown that Kalmegh can modulate

immune responses and inhibit viral replication, making it a candidate for managing viral infections (Bhaisare *et al*., 2023). Antimicrobial and Antioxidant Activities: The plant demonstrates significant antimicrobial properties against various pathogens and exhibits strong antioxidant effects, supporting its use in treating infections and oxidative stress-related conditions. Recent studies have highlighted the importance of nutrient management in Kalmegh cultivation. Applying foliar sprays of zinc and iron has been shown to enhance plant growth, chlorophyll content, and overall biomass, suggesting that micronutrient supplementation can improve yield and quality (Basak *et al*., 2020). Kalmegh (*Andrographis paniculata*) is a valuable herb with a diverse range of therapeutic applications, supported by a robust phytochemical profile and pharmacological evidence. Ongoing research continues to explore its potential in modern medicine, emphasizing the importance of sustainable cultivation practices to meet growing demand (Bhatnagar *et al*., 2023).

II. MATERIALS AND METHODS

Experimental site and soil: The field experiment was carried out at the Herbal Garden, Department of Plantation, Spices, Medicinal and Aromatic Crops, College of Horticulture, Mandsaur (M.P.) Crops, College of Horticulture, Mandsaur, under Rajmata Vijayaraje Scindia Krishi Vishwa Vidyalaya, Gwalior (M.P.) during kharif season of 2024-2025. The College of Horticulture, Mandsaur is situated in Malwa plateau in Western part of Madhya Pradesh at 23.45° to 24.13° North latitude, 74.44° to 75.18° East longitudes and at an altitude of 435 meters above mean sea level. This region falls under agro climatic zone No.9 of the State. Soil samples were collected from a depth of 10–15 cm at multiple locations across the experimental field, following standard sampling protocols prior to fertilizer application. A representative composite sample was prepared by thoroughly mixing the individual samples. Upon analysis, the soil was found to be light black and loamy in texture, characterized by low levels of available nitrogen and phosphorus, but a high potassium content.

Experimental design and treatments: The experiment was designed using Factorial Randomized Block Design (FRBD) and conducted in triplicate, with each plot covering an area of 4.32 m^2 (3.60 x 1.20 m) and Total experimental Area was 399.43 m^2 (14.96 × 26.70 m). The treatments are Main plots (04) Geometry: S_1 – 20 X 10, S_2 – 20 X 15, S_3 – 20 X 20, S_4 – 30 X 10 and Sub plots (04) N Sources: N_1- 40 kg N through Vermicompost + 40 kg N through Urea, N_2- 60 kg N through Vermicompost + 20 kg N through Urea, N_3- 80 kg N through Vermicompost, N_4- RDF (80 kg/ha N: 30 kg/ha P: 50 kg/ha K) NPK (80 kg/ha: 30 kg/ha: 50 kg/ha) and their 16 interactions are been observed..

Observations recorded: Observations on flowering parameters were recorded using standard methods. Key parameters included the morphological parameters such as Plant height (cm) at 30, 60, 90, 120 DAT and at harvest, Number of leaves ($Plant^{-1}$), Number of branches ($Plant^{-1}$), Five plants were randomly selected. They were measured at 30, 60, 90 and 120 DAT and at harvest. The plant height was measured from the ground level to the tip of the main shoot. The average was taken out and expressed as plant height in cm. The total number of leaves per plant was recorded at 30, 60, 90 and 120 DAT and at harvest and at harvest from the tagged plants and the average was worked out. The total number of primary branches per plant was recorded at 30, 60, 90 and 120 DAT and at harvest and at harvest from the tagged plants and the average was worked out. These measurements were taken from the net plot area of each treatment. The data for various parameters were analyzed using the analysis of variance method as outlined by (Panse and Sukhatme 1985).

Statistical analysis: The data recorded for different parameters were analyzed with the help of analysis of variance (ANOVA) technique for a randomized block design. The results are presented at 5% level of significance (P=0.05).

III. RESULTS AND DISCUSSION

Morphological parameters

Plant height (cm) at 30, 60, 90, 120 DAT and at harvest

The effects of nitrogen sources, planting geometries, and their interactions on plant height at different growth stages (30, 60, 90, 120 days after transplanting, and at harvest) were found to be significant. These results are summarized in Table 1 and illustrated in Figure 1.

(**30 DAT)** Among the planting geometry, S_1-20 X 10 cm produced the tallest plants (10.34 cm), followed by S_3-20 X 20 cm (9.63 cm) and S_2-20 X 15 cm (9.61 cm). The shortest plants were observed in S_4-30 X 10 cm (8.71 cm). Regarding nitrogen sources, N_1-40 kg N through vermicompost+40 kg N through urea exhibited the highest plant height (10.00 cm), followed by N3-80 kg N through vermicompost (9.99 cm). The shortest plant height (8.76 cm) was observed in N_2-60 kg N through vermicompost + 20 kg N through Urea. In the interaction, plant height ranged from 6.77 cm to 11.58 cm. The combination S_1 × N_1 produced the tallest plants (11.58 cm), followed by S_3 × N_1 (11.20 cm). On the other hand, the shortest plants (6.77 cm)

were observed with $S_3 \times N_2$. **(AT 60 DAT)** Among the main factors planting geometry, the tallest plants were recorded in S_1-20 X 10 cm (23.18 cm), followed by S_3-20 X 20 cm (22.28 cm) and S_2-20 X 15 cm (21.69 cm). The shortest plants were observed in S_4-30 X 10 cm (20.40 cm). Under sub factors nitrogen sources, N_1-40 kg N through vermicompost+40 kg N through urea accumulated the maximum plant height (22.87 cm), followed closely by N_3-80 kg N through vermicompost (22.59 cm). The shortest height was observed with N_2-60 kg N through vermicompost + 20 kg N through Urea (19.83 cm). During the interaction effects (S × N) showed a significant variation in plant height. The combination $S_1 \times N_1$ produced the tallest plants (26.43 cm), followed by $S_3 \times N_1$ (23.57 cm) and $S_1 \times N_3$ (23.77 cm). On the other hand, the shortest plants were recorded in $S_3 \times N_2$ (19.40 cm). **(AT 90 DAT)** Among the planting geometry, the tallest plants were recorded in S_1-20 X 10 cm (39.35 cm), followed by S_3-20 X 20 cm (37.91 cm) and S_2-20 X 15 cm (37.80 cm). The shortest plants were observed in S_4-30 X 10 cm (36.37 cm). Regarding nitrogen sources, N_1-40 kg N through vermicompost+40 kg N through urea exhibited the maximum plant height (38.84 cm), followed closely by N_3-80 kg N through vermicompost (38.63 cm). The shortest height was observed with N2-60 kg N through vermicompost + 20 kg N through Urea (36.09 cm). The interaction effects (S × N) showed a significant variation in plant height. The combination $S_1 \times N_1$ produced the tallest plants (42.26 cm), followed by $S_1 \times N_3$ (40.69 cm) and $S_3 \times N_4$ (40.77 cm). On the other hand, the shortest plants were recorded in $S_3 \times N_2$ (34.26 cm). **(AT 120)** In the planting geometry, the tallest plants were recorded in S1-20 X 10 cm (45.95 cm), followed by S_3-20 X 20 cm (45.24 cm) and S_2-20 X 15 cm (45.10 cm). The shortest plants were observed in S_4-30 X 10 cm (44.92 cm). Though, in the nitrogen sources, N_1-40 kg N through vermicompost+40 kg N through urea exhibited the maximum plant height (45.88 cm), followed by N_3-80 kg N through vermicompost (45.85 cm). The shortest height was observed with N_2- 60 kg N through vermicompost + 20 kg N through Urea (44.59 cm). The interaction effects (S × N) showed a significant variation in plant height. The combination $S_1 \times N_1$ produced the tallest plants (47.87 cm), followed by $S_3 \times N_3$ (46.33 cm) and $S_1 \times N_3$ (46.30 cm). On the other hand, the shortest plants were recorded in $S_3 \times N_2$ (42.62 cm). **(At harvest)** During the planting geometry, tallest plants were recorded in S_1-20 X 10 cm (50.37 cm), followed by S_3-20 X 20 cm (48.55 cm) and S_2-20 X 15 cm (48.39 cm). The shortest plants were observed in S_4-30 X 10 cm (47.48 cm). The sub plots as nitrogen sources, N_1-40 kg N through vermicompost+40 kg N through urea exhibited the maximum plant height (49.36 cm), followed closely by N_3-80 kg N through vermicompost (49.29 cm). The shortest height was observed with N_2-60 kg N through vermicompost + 20 kg N through Urea (47.31 cm). Regarding the interaction effects (S × N) showed a significant variation in plant height. The combination $S_1 \times N_1$ produced the tallest plants (53.25 cm), followed by $S_1 \times N_3$ (51.27 cm) and $S_3 \times N_4$ (51.02 cm). On the other hand, the shortest plants were recorded in $S_4 \times N_4$ (45.99 cm).

Plant height, a crucial morphological trait, was significantly affected by planting geometry, nitrogen sources, and their interaction across various growth stages. Among the planting geometries, S_1 (20 × 10 cm spacing) consistently resulted in the tallest plants, recording heights of 10.34, 23.18, 39.25, 45.95, and 50.37 cm at 30, 60, 90, 120 days after transplanting, and at harvest, respectively. This can be attributed to more efficient resource utilization and the close spacing, which encourages vertical growth by minimizing lateral competition. Conversely, the S_4 spacing (30 × 10 cm) produced the shortest plants, with corresponding heights of 8.71, 20.40, 36.37, 44.92, and 47.48 cm, likely due to reduced plant density and less competition, resulting in slower vertical development. Nitrogen source also played a significant role, with the highest plant height observed under the N_1 treatment (40 kg N from vermicompost + 40 kg N from urea), achieving 10.00, 22.87, 38.94, 45.88, and 49.36 cm at successive stages. In contrast, the lowest plant height was recorded with N_2 (60 kg N from vermicompost + 20 kg N from urea), measuring 8.76, 19.83, 36.09, 44.59, and 47.31 cm. The enhanced vegetative growth under N_1 can be attributed to the synergistic effect of combining organic and inorganic nitrogen sources, which improves nutrient availability and uptake. The interaction between spacing and nitrogen source further emphasized these trends. The combination $S_1 \times N_1$ produced the tallest plants—11.58, 26.43, 42.26, 47.87, and 53.25 cm—across the observed stages. In contrast, the $S_3 \times N_2$ combination resulted in the shortest plants, with heights of 6.77, 19.40, 34.26, 45.43, and 46.57 cm. These findings highlight the beneficial effects of closer spacing paired with balanced nutrient application on enhancing plant height. These results align with the findings of (Kumar *et al*., 2020), who reported that integrated nutrient management and optimized plant spacing significantly improve plant height in medicinal crops. Similar findings were also reported by (Cheena *et al*., 2020), (Mishra and Jain 2014), (Onsa *et al*., 2022) and (Shakywa *et al*., 2022).

Table 1: Effect of N sources, planting geometries, and their interactions on plant height (cm) at various growth stages in Kalmegh.

Treatments		30 DAT	60 DAT	90 DAT	120 DAT	At harvest
N Sources						
N_1	**40kg N by vermi +40 kg N by Urea**	10.00	22.87	38.84	45.88	49.36
N_2	**60kg N by vermi +20 kg N by Urea**	8.76	19.83	36.09	44.59	47.31
N_3	**80 kg N by Vermicompost**	9.99	22.59	38.63	45.85	49.29
N_4	**RDF**	9.55	22.25	37.87	44.89	48.82
S.Em ±		**0.16**	**0.24**	**0.50**	**0.18**	**0.34**
CD at 5%		**0.46**	**0.69**	**1.43**	**0.53**	**0.97**
Geometry						
S_1	**20 X 10 cm**	10.34	23.18	39.35	45.95	50.37
S_2	**20 X 15 cm**	9.61	21.69	37.80	45.10	48.39
S_3	**20 X 20 cm**	9.63	22.28	37.91	45.24	48.55
S_4	**30 X 10 cm**	8.71	20.40	36.37	44.92	47.48
S.Em ±		**0.16**	**0.24**	**0.50**	**0.18**	**0.34**
CD at 5%		**0.46**	**0.69**	**1.43**	**0.53**	**0.97**
Interaction S (Geometry) x N (Sources)						
$S_1 \times N_1$		11.58	26.43	42.26	47.87	53.25
$S_2 \times N_1$		9.17	21.84	38.71	45.45	48.41
$S_3 \times N_1$		11.20	23.57	39.17	46.25	49.27
$S_4 \times N_1$		8.03	19.63	35.23	43.95	46.52
$S_1 \times N_2$		8.98	20.10	36.18	45.43	46.81
$S_2 \times N_2$		8.93	20.33	36.29	45.43	46.57
$S_3 \times N_2$		6.77	19.40	34.26	42.62	46.30
$S_4 \times N_2$		10.36	19.49	37.61	44.87	49.55
$S_1 \times N_3$		10.86	23.77	40.69	46.30	51.27
$S_2 \times N_3$		9.93	22.43	39.51	45.03	50.47
$S_3 \times N_3$		9.83	22.80	37.43	45.73	47.59
$S_4 \times N_3$		9.32	21.36	36.90	46.33	47.84
$S_1 \times N_4$		9.93	22.40	38.27	44.20	50.16
$S_2 \times N_4$		10.39	22.17	36.69	44.47	48.11
$S_3 \times N_4$		10.72	23.33	40.77	46.37	51.02
$S_4 \times N_4$		7.14	21.10	35.73	44.53	45.99
S.Em ±		**0.32**	**0.48**	**0.99**	**0.37**	**0.67**
CD at 5%		**0.92**	**1.39**	**2.87**	**1.07**	**1.94**

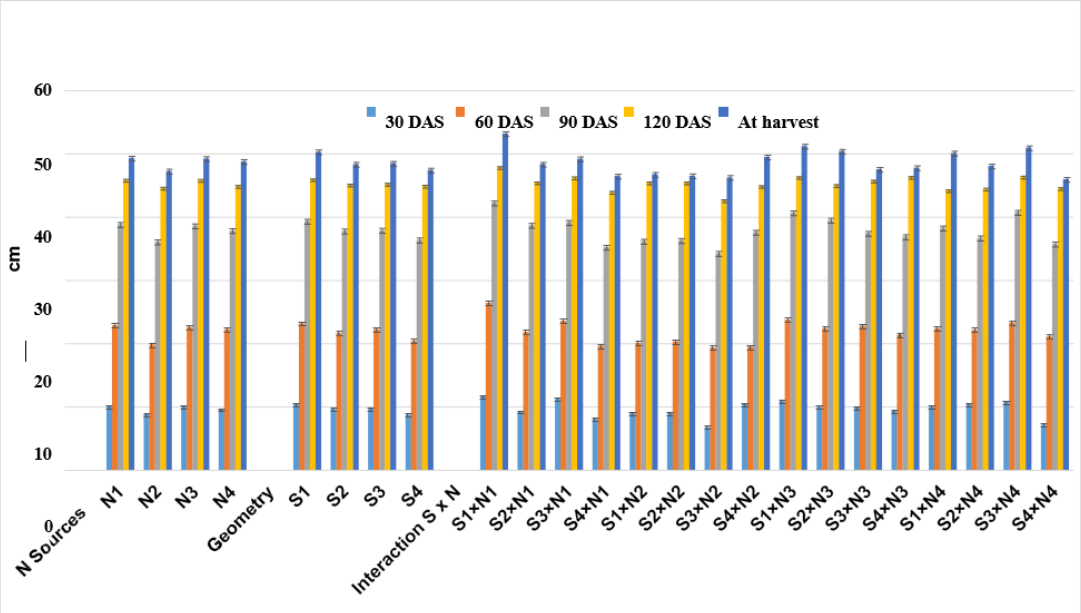

Fig.- 1 Effect of nitrogen sources, planting geometries, and their interactions on plant height (cm) at various growth stages in Kalmegh

Number of branches (plant^{1}) at 30, 60, 90, 120 DAT and at harvest

The number of branches was significantly affected by the application of different nitrogen sources and planting geometries across various growth stages (30, 60, 90, 120 days after transplanting, and at harvest). These results are presented in Table 2 and illustrated graphically in Figure 2.

(30 DAT) Among the planting geometry, the highest number of branches was recorded in S_1-20 X 10 cm (5.91), followed by S_3-20 X 20 cm (5.41) and S_2-20 X 15 cm (5.32). The lowest number of branches was recorded in S_4-30 X 10 cm (4.82), indicating that closer spacing in S1 promoted better branching. Regarding nitrogen sources, N_1-40 kg N through vermicompost+40 kg N through urea produced the highest number of branches (5.90), followed by N_3- 80 kg N through vermicompost (5.43). The lowest number of branches was recorded with N_2-60 kg N through vermicompost + 20 kg N through Urea (4.76). The interaction effects (S × N) showed significant variation in the number of branches. The combination $S_1 \times N_1$ produced the maximum number of branches (7.33), followed by $S_3 \times N_1$ (6.43) and $S_1 \times N_3$ (6.29). Conversely, the lowest number of branches was observed in $S_3 \times N_2$ (4.03). **(60 DAT)** Among the planting geometry, the maximum number of branches was observed in S_1-20 X 10 cm (14.31), followed by S_3-20 X 20 cm (13.33) and S_2- 20 X 15 cm (13.27). The lowest number of branches was recorded in S_4-30 X 10 cm (13.24), indicating that closer spacing in S_1 enhanced branching. Regarding nitrogen sources, N_1-40 kg N through vermicompost+40 kg N through urea recorded the highest number of branches (14.45), followed by N_3- 80 kg N through vermicompost (13.73). The lowest number of branches was observed with N_2-60 kg N through vermicompost + 20 kg N through Urea (12.87). The interaction effects (S × N) showed significant variation in the number of branches. The combination $S_1 \times N_1$ produced the highest number of branches (17.13), followed by $S_3 \times N_1$ (15.08) and $S_4 \times N_3$ (14.25). Conversely, the lowest number of branches was observed in $S_3 \times N_2$ (11.47). **(90 DAT)** During the planting geometry, the maximum number of branches was observed in S_1-20 X 10 cm (16.63), followed by S_3-20 X 20 cm (16.09) and S_2- 20 X 15 cm (16.07) while, S_4-30 X 10 cm (15.99) was showed lowest for the same treatment. Regarding nitrogen sources, N_1-40 kg N through vermicompost+40 kg N through urea recorded the highest number of branches (16.58), lagged behind the former closely by N_3-80 kg N through vermicompost (16.46) while, the lowest number of branches was observed with N_2-60 kg N through vermicompost + 20 kg N through Urea (15.76). The interaction effects (S × N) showed significant variation in the number of branches. The combination $S_1 \times N_1$ produced the highest number of branches (18.40), followed by $S_4 \times N_2$ (16.73) and $S_4 \times N_3$ (16.63). Conversely, the lowest number of branches was observed in S3 × N2 (15.00). **(At 120 DAT)** Among the planting geometry, the

highest number of branches was observed in S_1-20 X 10 cm (17.65), followed by S_3-20 X 20 cm (16.73) and S_2- 20 X 15 cm (16.70). The lowest number of branches was recorded in S_4-30 X 10 cm (16.44). Regarding nitrogen sources, N_1-40 kg N through vermicompost+40 kg N through urea recorded the highest number of branches (17.58), second highest N_3-80 kg N through vermicompost (17.21). The lowest number of branches was accumulated with N_2-60 kg N through vermicompost + 20 kg N through Urea (16.13). The interaction effects (S × N) showed significant variation in the number of branches. The combination S_1 × N_1 produced the highest number of branches (20.00), followed by S_1 × N_3 (18.90) and S_3 × N_4 (18.13). Conversely, the lowest number of branches was observed in S_3 × N_2 (14.50). **(At harvest)** Among the planting geometry, the maximum number of branches was observed in S_1-20 X 10 cm (19.18), followed by S_3-20 X 20 cm (18.31) and S_2- 20 X 15 cm (18.27). The lowest number of branches was recorded in S_4-30 X 10 cm (18.23). Regarding nitrogen sources, N_1-40 kg N through vermicompost+40 kg N through urea recorded the greater number of branches (19.23), came after the highest N_3-80 kg N through vermicompost (18.72) while less with N_2-60 kg N through vermicompost + 20 kg N through Urea (17.71). The interaction effects (S × N) showed significant variation in the number of branches. The combination S_1 × N_1 produced the highest number of branches (20.53), followed by S_1 × N_3 (19.67) and S_3 × N_4 (19.13). Conversely, the lowest number of branches was observed in S_3 × N_2 (16.47).

The number of branches per plant serves as a key indicator of vegetative growth and overall plant health. This trait was significantly influenced by planting geometry, nitrogen sources, and their interaction across all growth stages. Among the planting geometries, S_1 (20 × 10 cm spacing) consistently recorded the highest number of branches—5.91, 14.31, 16.63, 17.65, and 19.18 at 30, 60, 90, 120 days after transplanting, and at harvest, respectively. This increased branching is likely a result of greater inter-plant competition for light under closer spacing, which promotes lateral growth. On the other hand, S_4 (30 × 10 cm) produced fewer branches—4.82, 13.24, 15.99, 16.44, and 18.23 at the corresponding growth stages—possibly due to lower plant density and reduced competition. Regarding nitrogen treatments, N_1 (40 kg N through vermicompost + 40 kg N through urea) led to the highest number of branches—5.90, 14.45, 16.58, 17.58, and 19.23—highlighting the importance of a balanced nitrogen supply for optimal vegetative development. In contrast, N_2 (60 kg N through vermicompost + 20 kg N through urea) recorded the lowest values—4.76, 12.87, 15.76, 16.13, and 17.71—indicating comparatively weaker vegetative performance. The interaction between planting geometry and nitrogen source further reinforced these findings. The S_1 × N_1 combination yielded the highest number of branches across all stages—7.33, 17.13, 18.40, 20.00, and 20.53—demonstrating the positive effect of close spacing combined with a well-balanced nitrogen regimen. Conversely, the S_3 × N_2 treatment produced the fewest branches—4.03, 11.47, 15.00, 14.50, and 16.47—across the respective stages. These results underscore the synergistic influence of optimal spacing and nutrient management on enhancing branching and overall vegetative vigor. These findings corroborate those of (Patel *et al.* 2019), (Cheena *et al.*, 2020), (Mishra and Jain 2014), (Semwal *et al.*, 2016) and (Chouhan *et al.*, 2023) who noted similar trends in other medicinal crops under integrated nutrient management systems.

Table 2: Effect of N sources, planting geometries, and their interactions on number of branches at various growth stages in Kalmegh.

Treatments		30 DAT	60 DAT	90 DAT	120 DAT	At harvest
N Sources						
N_1	**40kg N by vermi +40 kg N by Urea**	5.90	14.45	16.58	17.58	19.23
N_2	**60kg N by vermi +20 kg N by Urea**	4.76	12.87	15.76	16.13	17.71
N_3	**80 kg N by Vermi**	5.43	13.73	16.46	17.21	18.72
N_4	**RDF**	5.37	13.11	15.99	16.60	18.33
S.Em ±		**0.14**	**0.22**	**0.15**	**0.25**	**0.27**
CD at 5%		**0.40**	**0.64**	**0.42**	**0.71**	**0.78**
Geometry						
S_1	**20 X 10 cm**	5.91	14.31	16.63	17.65	19.18
S_2	**20 X 15 cm**	5.32	13.27	16.07	16.70	18.27
S_3	**20 X 20 cm**	5.41	13.33	16.09	16.73	18.31

S_4	**30 X 10 cm**	4.82	13.24	15.99	16.44	18.23
S.Em ±		**0.14**	**0.22**	**0.15**	**0.25**	**0.27**
CD at 5%		**0.40**	**0.64**	**0.42**	**0.71**	**0.78**
Interaction S (Geometry) x N (Sources)						
$S_1 \times N_1$		7.33	17.13	18.40	20.00	20.53
$S_2 \times N_1$		5.63	12.92	15.90	17.20	19.23
$S_3 \times N_1$		6.43	15.08	16.53	16.93	19.37
$S_4 \times N_1$		4.21	12.67	15.47	16.20	17.77
$S_1 \times N_2$		4.73	12.80	15.63	16.30	17.83
$S_2 \times N_2$		4.97	13.06	15.67	16.37	17.87
$S_3 \times N_2$		4.03	11.47	15.00	14.50	16.47
$S_4 \times N_2$		5.30	14.16	16.73	17.33	18.67
$S_1 \times N_3$		6.29	13.97	16.57	18.90	19.67
$S_2 \times N_3$		5.47	13.59	16.20	15.17	18.47
$S_3 \times N_3$		5.30	13.12	16.43	17.33	18.27
$S_4 \times N_3$		4.67	14.25	16.63	17.43	18.47
$S_1 \times N_4$		5.30	13.37	15.93	15.40	18.67
$S_2 \times N_4$		5.20	13.50	16.50	18.07	17.50
$S_3 \times N_4$		5.87	13.67	16.40	18.13	19.13
$S_4 \times N_4$		5.10	11.90	15.13	14.80	18.00
S.Em ±		**0.28**	**0.45**	**0.29**	**0.49**	**0.54**
CD at 5%		**0.81**	**1.29**	**0.85**	**1.43**	**1.55**

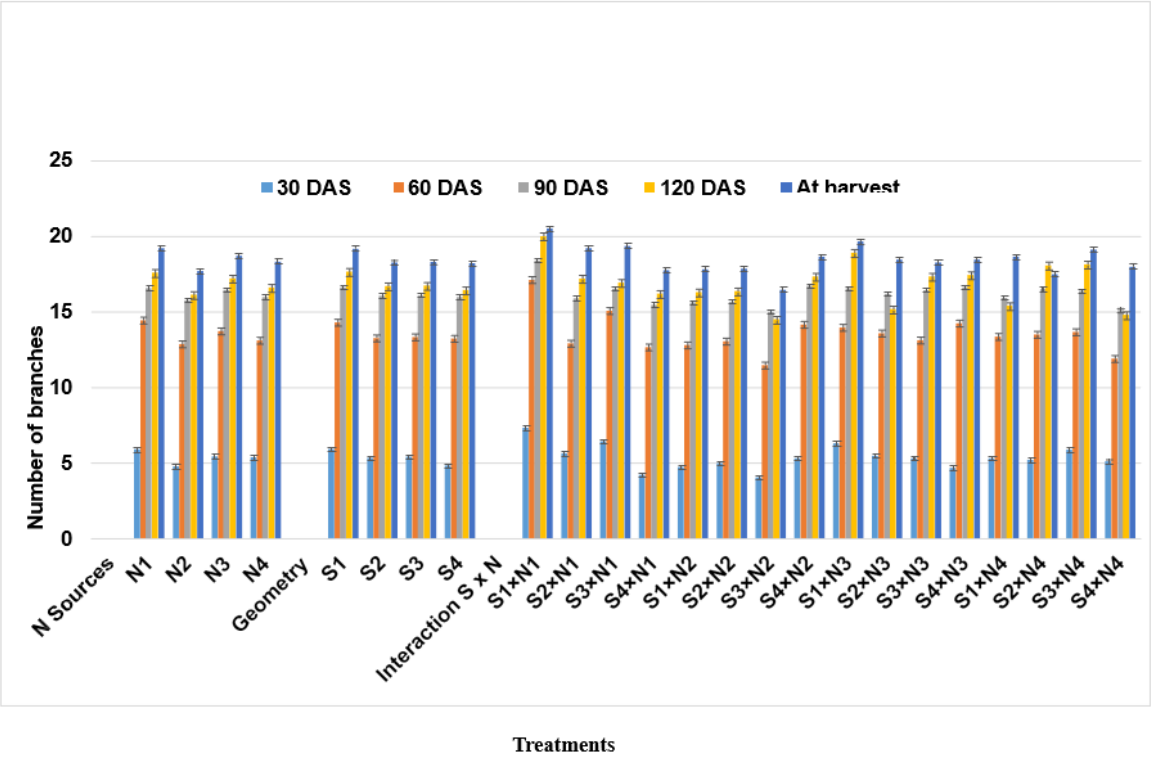

Fig.-2 Effect of nitrogen sources, planting geometries, and their interactions on number of branches (plant^{-1}) at various growth stages in Kalmegh.

Number of leaves (plant^{-1}) at 30, 60, 90, 120 DAT and at harvest

Nitrogen sources, planting geometries, and their interactions had a significant impact on the number of leaves at various growth stages (30, 60, 90, 120 days after transplanting, and at harvest). These findings are summarized in Table 3 and visually represented in Figure 3.

(30 DAT) Among the main factors as planting geometry, the highest number of leaves was recorded in S_1-20 X 10 cm (29.03), followed by S_3-20 X 20 cm (28.31) and S_2-20 X 15 cm (27.99). The lowest number of leaves was observed in S_4-30 X 10 cm (27.67) under sub factor as nitrogen sources, N_1-40 kg N through vermicompost+40 kg N through urea recorded the maximum number of leaves (29.03), lagged behind the former N_3-80 kg N through vermicompost (28.44). The lowest number of leaves was observed with N_2-60 kg N through vermicompost + 20 kg N through Urea (27.16). The interaction effects (S × N) showed significant variation in the number of leaves. The combination $S_1 \times N_1$ produced the highest number of leaves (31.23), followed by $S_3 \times N_4$ (29.20) and $S_3 \times N_1$ (29.63). Conversely, the lowest number of leaves was recorded in $S_3 \times N_2$ (26.63). **(60 DAT)** Among the main factor as planting geometry, the maximum number of leaves was observed in S_1-20 X 10 cm (170.76), followed by S_3-20 X 20 cm (165.73) and S_2-20 X 15 cm (165.25). The lowest number of leaves was recorded in S_4-30 X 10 cm (160.46) under sub factor as nitrogen sources, N_1- 40 kg N through vermicompost+40 kg N through urea recorded the highest number of leaves (168.82), followed by N_3-80 kg N through vermicompost (166.53). The lowest number of leaves while less with N_2-60 kg N through vermicompost + 20 kg N through Urea (161.43). During The interaction effects (S × N) exhibited significant variation. The combination $S_1 \times N_1$ produced the highest number of leaves (176.87), followed by $S_1 \times N_3$ (173.13) and $S_3 \times N_4$ (172.40). On the other hand, the lowest number of leaves was recorded in $S_4 \times N_3$ (155.13). **(90 DAT)** Among the main factor as planting geometry, the maximum number of leaves was observed in S_1-20 X 10 cm (197.76), followed by S_3-20 X 20 cm (195.23) and S_2-20 X 15 cm (194.88). The lowest number of leaves was recorded in S_4-30 X 10 cm (193.48). Under sub factor nitrogen sources, N_1-40 kg N through vermicompost+40 kg N through urea recorded the highest number of leaves (197.25), came after the highest N_3-80 kg N through vermicompost (197.10). The nitrogen sources N_2-60 kg N through vermicompost + 20 kg N through Urea (193.45) showed a lower number of leaves. The interaction effects (S × N) exhibited statistically variations. The combination $S_1 \times N_1$ produced the highest number of leaves (202.84), followed by $S_1 \times N_3$ (202.07) and $S_3 \times N_4$ (200.27). On the other hand, the lowest number of leaves was recorded in $S_4 \times N_4$ (187.20). **(120 DAT)** The planting geometry, the maximum number of leaves was recorded in S1-20 X 10 cm (215.48), followed by S_3-20 X 20 cm (212.69) and S2-20 X 15 cm (212.43). The least number of leaves was observed in S_4-30 X 10 cm (211.73) under sub factors as nitrogen sources, N_1-40 kg N through vermicompost+40 kg N through urea produced the highest number of leaves (215.25), followed closely by N_3-80 kg N through vermicompost (215.11). N_2- 60 kg N through vermicompost + 20 kg N through Urea had the lowest (209.52). The interaction effects (S × N) exhibited significant variation. The combination $S_1 \times N_1$ resulted in the maximum number of leaves (221.47), followed by $S_1 \times N_3$ (221.07) and $S_3 \times N_4$ (219.27). On the other hand, the lowest number of leaves was observed in $S_3 \times N_2$ (205.43). (At harvest) In terms of planting geometry, the highest number of leaves was recorded in S_1-20 X 10 cm (142.83), followed by S_3-20 X 20 cm (140.58) and S_2-20 X 15 cm (137.92). The lowest value was observed in S_4-30 X 10 cm (137.71). Under the nitrogen sources, N_1-40 kg N through vermicompost+40 kg N through urea exhibited the highest number of leaves (143.38), followed closely by N_3-80 kg N through vermicompost (141.92). The lowest number of leaves was recorded with N_2-60 kg N through vermicompost + 20 kg N through Urea (136.42). The interaction effects (S × N) revealed statistically variation. The combination $S_1 \times N_1$ produced the highest number of leaves (152.33), followed by $S_1 \times N_3$ (146.33) and $S_3 \times N_1$ (145.67). On the contrary, the lowest number of leaves was recorded in $S_2 \times N_4$ (128.00).

The number of leaves per plant varied significantly in response to planting geometry, nitrogen sources, and their interaction. Among the spacing treatments, S_1 (20 × 10 cm) recorded the highest number of leaves—29.03, 170.76, 197.76, 215.48, and 142.83 at 30, 60, 90, 120 days after transplanting, and at harvest, respectively—likely due to higher plant density and more efficient utilization of available resources. In contrast, S_4 (30 × 10 cm) resulted in the lowest leaf count—27.67, 160.46, 193.48, 211.73, and 137.71—possibly due to wider spacing and reduced inter-plant competition. With respect to nitrogen treatments, N_1 (40 kg N from vermicompost + 40 kg N from urea) produced the highest number of leaves—29.03, 168.82, 197.25, 215.35, and 143.38—demonstrating the benefits of balanced fertilization in promoting vegetative growth. On the other hand, N_2 (60 kg N from vermicompost + 20 kg N from urea) resulted in the lowest leaf numbers—27.16, 161.43, 193.45, 209.52, and 136.42—at the respective growth stages. The interaction effects further supported these trends. The $S_1 \times N_1$ combination led to the maximum

number of leaves—31.23, 176.87, 202.84, 221.47, and 152.33—across all stages, indicating the synergistic benefits of close spacing and integrated nutrient management. Conversely, the $S_3 \times N_2$ treatment produced the fewest leaves—26.63, 156.60, 190.13, 205.43, and 132.33—confirming the reduced effectiveness of wider spacing combined with less balanced fertilization. These results are consistent with the findings of (Sharma *et al.* 2021). Similar findings were also reported by (Cheena *et al.*, 2020), (Mishra and Jain 2014), (Salmaben *et al*., 2022) and (Shakywa *et al*., 2022) who highlighted the significance of plant spacing and nutrient management in improving leaf development.

Table 3:- Effect of N sources, planting geometries, and their interactions on number of leaves (plant^{-1}) at various growth stages in Kalmegh.

Treatments		30 DAT	60 DAT	90 DAT	120 DAT	At harvest
N Sources						
N_1	**40kg N by vermi +40 kg N by Urea**	29.03	168.82	197.25	215.25	143.38
N_2	**60kg N by vermi +20 kg N by Urea**	27.16	161.43	193.45	209.52	136.42
N_3	**80 kg N by Vermi**	28.44	166.53	197.10	215.11	141.92
N_4	**RDF**	28.37	165.43	193.56	212.46	137.33
S.Em ±		**0.20**	**1.56**	**0.94**	**1.20**	**1.46**
CD at 5%		**0.57**	**4.52**	**2.71**	**3.48**	**4.21**
Geometry						
S_1	**20 X 10 cm**	29.03	170.76	197.76	215.48	142.83
S_2	**20 X 15 cm**	27.99	165.25	194.88	212.43	137.92
S_3	**20 X 20 cm**	28.31	165.73	195.23	212.69	140.58
S_4	**30 X 10 cm**	27.67	160.46	193.48	211.73	137.71
S.Em ±		**0.20**	**1.56**	**0.94**	**1.20**	**1.46**
CD at 5%		**0.57**	**4.52**	**2.71**	**3.48**	**4.21**
Interaction S (Geometry) x N (Sources)						
$S_1 \times N_1$		31.23	176.87	202.84	221.47	152.33
$S_2 \times N_1$		28.33	165.33	197.90	218.23	142.67
$S_3 \times N_1$		29.63	168.07	195.73	215.73	145.67
$S_4 \times N_1$		26.93	165.00	192.53	205.57	132.83
$S_1 \times N_2$		27.03	165.20	192.93	206.43	133.00
$S_2 \times N_2$		27.10	165.37	193.20	207.47	139.67
$S_3 \times N_2$		26.63	156.60	190.13	205.43	132.33
$S_4 \times N_2$		27.87	158.57	197.53	218.73	140.67
$S_1 \times N_3$		29.47	173.13	202.07	221.07	146.33
$S_2 \times N_3$		28.67	171.97	194.87	213.57	141.33
$S_3 \times N_3$		27.77	165.87	194.80	210.33	140.33
$S_4 \times N_3$		27.87	155.13	196.67	215.47	139.67
$S_1 \times N_4$		28.40	167.83	193.20	212.93	139.67
$S_2 \times N_4$		27.87	158.33	193.57	210.47	128.00
$S_3 \times N_4$		29.20	172.40	200.27	219.27	144.00
$S_4 \times N_4$		28.00	163.13	187.20	207.17	137.67
S.Em ±		**0.39**	**3.13**	**1.88**	**2.41**	**2.91**
CD at 5%		**1.13**	**9.04**	**5.42**	**6.95**	**8.42**

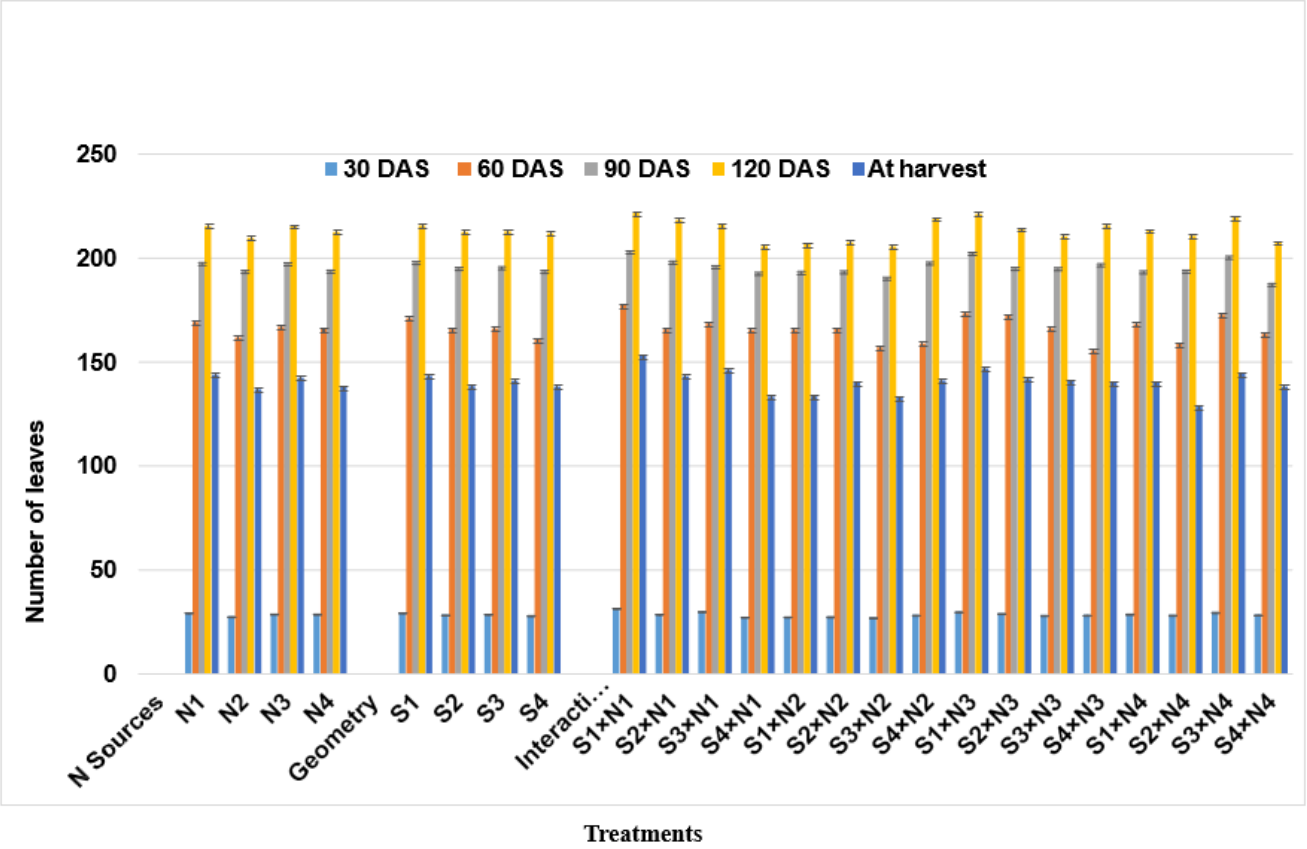

Fig.- 3 Effect of nitrogen sources, planting geometries, and their interactions on number of leaves (plant-1) at various growth stages in Kalmegh.

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International Journal of Environment, Agriculture and Biotechnology
Vol-10, Issue-3; May-Jun, 2025
Peer-Reviewed International Journal
Journal Home Page Available: https://ijeab.com/
Journal DOI: 10.22161/ijeab

Impact of Different Nitrogen Sources and Plant Spacing on the Growth Characteristics of Kalmegh (*Andrographis paniculata* Nees) under the Malwa Agro-Climatic Region of Madhya Pradesh

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Received: 04 Apr 2025; Received in revised form: 05 May 2025; Accepted: 13 May 2025; Available online: 17 May 2025

Abstract— *A field experiment titled "Effect of Nitrogen Sources and Plant Geometry on Herbage Yield and Nutrient Uptake in Kalmegh (Andrographis paniculata Nees.) under the Malwa Plateau of Madhya Pradesh" was conducted during the Kharif season of 2024–25. The study was undertaken at the Herbal Garden, Department of Plantation, Spices, Medicinal and Aromatic Crops, KNK College of Horticulture, Mandsaur (M.P.). Observations on various growth parameters were systematically recorded using established scientific methodologies. The study assessed key growth parameters, including Leaf Area (cm^2 plant^{-1}) Fresh weight (g plant^{-1}) and Dry weight (g plant^{-1}). Observations were recorded from five randomly selected plants at intervals of 30, 60, 90, and 120 days after transplanting (DAT), as well as at the time of harvest. The results indicated that among the nitrogen treatments, N_1 (40 kg N through vermicompost + 40 kg N through urea) showed the highest values for leaf area (8.75, 45.10, 104.54, 134.45, and 134.37 cm²), fresh weight (9.13, 25.51, 45.00, 64.41, and 63.72 g), and dry weight (2.68, 6.81, 23.06, 41.77, and 44.17 g). In terms of plant spacing, the S_1 geometry (20 × 10 cm) resulted in the greatest leaf area (9.12, 45.80, 105.33, 135.12, and 134.43 cm²), fresh weight (9.22, 26.70, 45.15, 64.95, and 64.34 g), and dry weight (2.76, 6.92, 22.98, 41.70, and 44.22 g). Furthermore, the combined treatment of S_1 × N_1 produced the most significant results, with maximum leaf area (10.82, 48.23, 108.83, 139.01, and 137.53 cm²), fresh weight (10.50, 32.49, 48.83, 68.50, and 70.06 g), and dry weight (3.49, 8.54, 28.68, 46.61, and 47.79 g) at 30, 60, 90 DAT, and at harvest.*

Keywords— ***Kalmegh, nitrogen sources, plant spacing, leaf area, biomass production***

I. INTRODUCTION

Kalmegh (*Andrographis paniculata*), a significant medicinal plant from the Acanthaceae family, holds a prominent place in traditional and modern herbal medicine. The *Andrographis* genus, native to India, comprises around 40 species globally, with 19 found in India. Among these, only *A. paniculata* and *A. alata* are recognized for their distinct medicinal properties (Farooqi et al., 2010). Kalmegh is an herbaceous annual plant that can reach a height of up to 110 cm. Recognizing its therapeutic importance, the National Medicinal Plant Board has listed Kalmegh 17th among 32 prioritized medicinal species (NMPB, 2014). It plays a crucial role in Indian pharmacopoeia and features in 26 Ayurvedic formulations (Verma *et al*., 2018). Kalmegh is the key ingredient in "Alui," a traditional remedy widely used in West Bengal to treat dyspepsia and general weakness in both adults and

children. Known for its potent antipyretic and antiviral properties, Kalmegh has even been cited as a potential aid in combating COVID-19 (Verma *et al*., 2021). Its therapeutic uses extend across China, India, and other Southeast Asian countries, where it is employed in treating ailments like fever, colds, laryngitis, malaria, dysentery, and diarrhea. The plant also exhibits antibacterial, anti-inflammatory, antithrombotic, and immune-boosting effects (Verma *et al*., 2024). As the demand for herbal medicines and health supplements continues to rise, there is a growing emphasis on cultivating medicinal plants that are safe, high in quality, and free from harmful chemicals. Consequently, reducing chemical inputs in Kalmegh cultivation is critical, with a shift toward organic practices gaining momentum. Organic liquid manures and bioformulations offer safer, eco-friendly alternatives, making them ideal for a plant used in both Ayurvedic and pharmaceutical applications. Furthermore, the use of organic inputs and microbial inoculants not only improves fertilizer efficiency but also enhances soil health by improving its physicochemical and biological properties (Trisilawati *et al*., 2019). Nitrogen is especially vital for Kalmegh, as it supports chlorophyll production, protein synthesis, and overall vegetative growth, which directly impacts the development of leaves and stems—the main reservoirs of its key bioactive compound, andrographolide (Kumar *et al*., 2018; Verma *et al*., 2024). Proper nitrogen nutrition contributes to increased biomass and better yields, but a balanced approach is essential. Over-application may lead to lush vegetative growth at the cost of reduced medicinal quality. Thus, efficient nitrogen management is crucial for optimizing both yield and therapeutic efficacy (Shakywa *et al*., 2022; Pandey *et al*., 2025). Given the increasing demand for herbal products across global pharmaceutical and Ayurvedic sectors, Kalmegh is poised to become a highly valuable crop. In light of this, the present study has been designed to explore the plant's response to various nitrogen sources and application methods, as these factors play a significant role in influencing its growth, yield, and medicinal quality (Sharangi *et al*., 2025).

II. MATERIALS AND METHODS

Experimental site and soil: The field experiment was conducted during the Kharif season of 2024–2025 at the Herbal Garden, Department of Plantation, Spices, Medicinal and Aromatic Crops, College of Horticulture, Mandsaur, which operates under Rajmata Vijayaraje Scindia Krishi Vishwa Vidyalaya, Gwalior (M.P.). The experimental site is located on the Malwa Plateau in the western region of Madhya Pradesh, positioned between 23.45° to 24.13° North latitude and 74.44° to 75.18° East longitude, at an elevation of 435 meters above mean sea level. This area falls within Agro-Climatic Zone 9 of the state. Prior to fertilizer application, soil samples were collected from a depth of 10–15 cm at various points across the field using standard sampling techniques. These samples were combined to form a representative composite sample through thorough mixing. Soil analysis revealed a light black, loamy texture with low levels of available nitrogen and phosphorus but high potassium content.

Experimental design and treatments: The experiment was laid out using a Factorial Randomized Block Design (FRBD) and replicated three times. Each individual plot measured 4.32 m² (3.60 m × 1.20 m), while the total experimental area covered 399.43 m² (14.96 m × 26.70 m). The study included two factors: plant geometry as the main plot treatment with four spacings — S_1: 20 × 10 cm, S_2: 20 × 15 cm, S_3: 20 × 20 cm, and S_4: 30 × 10 cm; and nitrogen sources as subplot treatments with four levels — N_1: 40 kg N from vermicompost + 40 kg N from urea, N_2: 60 kg N from vermicompost + 20 kg N from urea, N_3: 80 kg N from vermicompost, and N_4: recommended dose of fertilizers (RDF) consisting of 80 kg/ha N, 30 kg/ha P, and 50 kg/ha K. A total of 16 treatment combinations resulting from the interaction of these factors were evaluated.

Observations recorded: Growth parameter observations were recorded using standardized procedures. The primary parameters assessed included leaf area (cm² per plant), fresh weight (g per plant), and dry weight (g per plant). For each treatment, five plants were randomly selected and measurements were taken at 30, 60, 90, and 120 days after transplanting (DAT), as well as at harvest. Leaves were detached from the sampled plants and their area was measured using a leaf area meter (LAM 211), with results expressed in cm² per plant for each observation stage. The entire fresh herb from each labeled plant was harvested and weighed using an electronic balance, with the average calculated and recorded in grams per plant. For dry weight determination, the harvested herbs from five tagged plants were dried in a hot air oven at 65°C until a constant weight was achieved, then weighed with an electronic balance and expressed as the mean dry weight in grams. All measurements were taken from the net plot area for each treatment. The collected data were subjected to analysis of variance (ANOVA) following the method described by Panse and Sukhatme (1985).

Statistical analysis: The data recorded for different parameters were analyzed with the help of analysis of variance (ANOVA) technique for a randomized block design. The results are presented at 5% level of significance (P=0.05).

III. RESULTS AND DISCUSSION

Morphological parameters

Leaf area (cm^2) at 30, 60, 90, 120 DAT and at harvest

The leaf area of the Kalmegh plant was significantly affected by the application of nitrogen, the different planting geometries, and their combined interactions at various stages of growth (30, 60, 90, and 120 days after transplanting (DAT), as well as at harvest). This is clearly demonstrated in Table 1 and Fig. 1, which highlight the variations observed in leaf area across these factors. At 30 days after transplanting (DAT), among the different planting geometries, the highest leaf area was observed in S_1 (20 × 10 cm) with 9.12 cm², followed by S_3 (20 × 20 cm) at 8.28 cm², and S_2 (20 × 15 cm) at 8.27 cm², while the lowest was recorded in S_4 (30 × 10 cm) with 7.75 cm². In terms of nitrogen sources, N_1 (40 kg N from vermicompost + 40 kg N from urea) showed the maximum leaf area of 8.75 cm², closely followed by N_3 (80 kg N from vermicompost) at 8.71 cm², while N_2 (60 kg N from vermicompost + 20 kg N from urea) recorded the lowest at 7.51 cm². The interaction between planting geometry and nitrogen sources was significant, with $S_1 \times N_1$ producing the highest leaf area of 10.82 cm², and the lowest recorded in $S_4 \times N_1$ at 7.12 cm². At 60 DAT, S_1 (20 × 10 cm) again showed the highest leaf area (45.80 cm²), followed by S3 (44.31 cm²) and S2 (44.06 cm²), with S4 recording the lowest (43.42 cm²). Among nitrogen treatments, N_1 again led with 45.10 cm², followed closely by N_3 (45.01 cm²), and the lowest was seen in N_2 (42.94 cm²). The $S_1 \times N_1$ combination produced the highest leaf area (48.23 cm²), while $S_3 \times N_2$ showed the lowest (41.44 cm²). At 90 DAT, the trend continued, with S1 leading in leaf area (105.33 cm²), followed by S_3 (103.80 cm²) and S_2 (103.22 cm²), and S4 being the lowest (102.91 cm²). N_1 and N_3 again recorded the highest values (104.54 and 104.48 cm², respectively), and N_2 the lowest (102.46 cm²). The interaction $S_1 \times N_1$ recorded the maximum (108.83 cm²), followed by $S_1 \times N_3$ (106.45 cm²) and $S_3 \times N_4$ (106.05 cm²). The lowest was observed in $S_3 \times N_2$ (101.41 cm²). At 120 DAT, S_1 (135.12 cm²) maintained the highest leaf area, followed by S3 (133.15 cm²) and S_2 (132.93 cm²), with S_4 again the lowest (132.78 cm²). Among nitrogen sources, N_1 remained highest (134.45 cm²), with N_3 close behind (134.30 cm²) and N_2 lowest (131.26 cm²). The $S_1 \times N_1$ interaction yielded the maximum leaf area (139.01 cm²), followed by $S_1 \times N_3$ (137.04 cm²) and $S_3 \times N_4$ (136.33 cm²). The lowest was in $S_3 \times N_2$ (129.40 cm²). At harvest, S_1 again recorded the highest leaf area (134.43 cm²), followed by S_3 (133.04 cm²) and S_2 (132.87 cm²), with S_4 being the lowest (132.22 cm²). N_1 resulted in the highest leaf area (134.37 cm²), followed by N_3 (134.14 cm²) and N_2 (131.00 cm²) as the lowest. The $S_1 \times N_1$ treatment remained the top performer (137.53 cm²), followed by $S_2 \times N_3$ (135.88 cm²) and $S_3 \times N_1$ (135.77 cm²). The lowest values were noted in $S_4 \times N_2$ and $S_2 \times N_4$ (both 129.10 cm²). The results show that nitrogen application influenced leaf area positively, with treatments involving higher nitrogen doses generally leading to larger leaf areas. Similarly, the planting geometry also played a crucial role in determining leaf area, with certain spacing configurations leading to better leaf expansion. The interaction between nitrogen sources and planting geometry further impacted the growth, producing varying results at different growth stages. At each observation point, the combination of these factors resulted in a significant variation in leaf area, underscoring the importance of optimizing both nitrogen levels and planting geometry for maximum growth potential in Kalmegh cultivation.These results align with findings by Sadashiv *et al*. (2007), who reported that vermicompost application enhanced plant height, branching, and leaf area in Coleus (*Coleus forskohlii*). Similarly, Kumar *et al*. (2018) attributed increased leaf expansion to higher nitrogen uptake and availability, supporting the outcomes observed in this study.

Table 1:- Effect of nitrogen sources, planting geometries, and their interactions on leaf area (cm^2) at various growth stages in Kalmegh.

Treatments		30 DAT	60 DAT	90 DAT	120 DAT	At harvest
N Sources						
N1	**40kg N by vermi +40 kg N by Urea**	8.75	45.10	104.54	134.45	134.37
N2	**60kg N by vermi +20 kg N by Urea**	7.51	42.94	102.46	131.26	131.00
N3	**80 kg N by Vermi**	8.71	45.01	104.48	134.30	134.14
N4	**RDF**	8.45	44.55	103.78	133.98	133.07
S.Em ±		**0.22**	**0.48**	**0.38**	**0.64**	**0.22**

CD at 5%		**0.64**	**1.40**	**1.09**	**1.86**	**0.64**
Geometry						
S1	**20 X 10 cm**	9.12	45.80	105.33	135.12	134.43
S2	**20 X 15 cm**	8.27	44.06	103.22	132.93	132.87
S3	**20 X 20 cm**	8.28	44.31	103.80	133.15	133.04
S4	**30 X 10 cm**	7.75	43.42	102.91	132.78	132.22
S.Em ±		**0.22**	**0.48**	**0.38**	**0.64**	**0.22**
CD at 5%		**0.64**	**1.40**	**1.09**	**1.86**	**0.64**
Interaction S (Geometry) x N (Sources)						
S1×N1		10.82	48.23	108.83	139.01	137.53
S2×N1		8.59	44.18	103.37	134.73	134.99
S3×N1		8.47	45.07	104.23	134.59	135.77
S4×N1		7.12	42.93	101.71	129.47	129.20
S1×N2		7.41	43.07	102.09	130.48	129.54
S2×N2		7.76	43.17	102.25	130.68	131.53
S3×N2		6.78	41.44	101.41	129.40	129.10
S4×N2		8.08	44.08	104.10	134.47	133.81
S1×N3		9.40	46.73	106.45	137.04	135.67
S2×N3		8.97	45.60	104.00	134.00	135.88
S3×N3		8.50	44.10	103.50	132.28	131.80
S4×N3		7.98	43.60	103.98	133.86	133.21
S1×N4		8.85	45.18	103.97	133.94	135.00
S2×N4		7.75	43.30	103.24	132.30	129.10
S3×N4		9.38	46.64	106.05	136.33	135.51
S4×N4		7.82	43.07	101.84	133.34	132.66
S.Em ±		**0.44**	**0.97**	**0.75**	**1.29**	**0.45**
CD at 5%		**1.28**	**2.80**	**2.18**	**3.72**	**1.29**

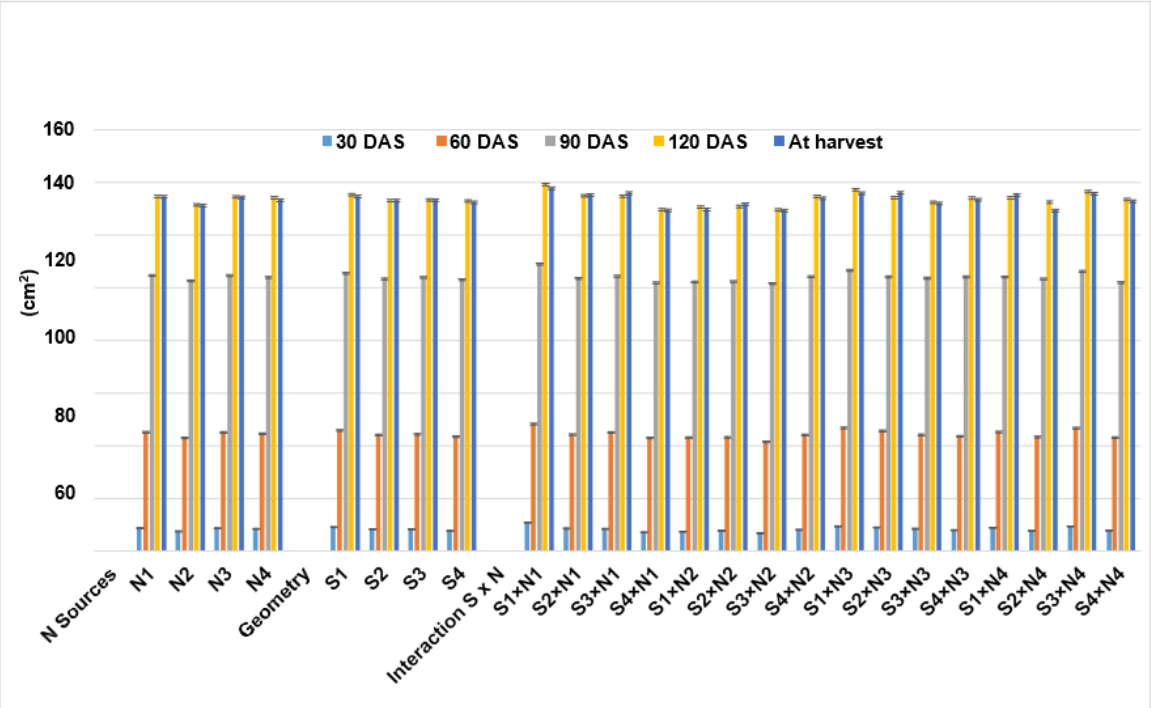

Fig.- 1 Effect of nitrogen sources, planting geometries, and their interactions on leaf area (cm^2) at various growth stages in Kalmegh.

Fresh weight (g plant^{-1}) at 30, 60, 90, 120 DAT and at harvest

The fresh weight of Kalmegh plants was significantly influenced by the nitrogen sources, planting geometries, and their interactions at different growth stages (30, 60, 90, 120 DAT, and at harvest), as shown in Table 2 and depicted in Fig. 2. **At 30 DAT**, the highest fresh weight was observed in the S_1-20 x 10 cm planting geometry (9.22 g), followed by S_3-20 x 20 cm (8.72 g) and S_2-20 x 15 cm (8.32 g). The lowest fresh weight was recorded in S_4-30 x 10 cm (8.21 g). Among the nitrogen treatments, the highest fresh weight (9.13 g) was achieved with N_1, which provided 40 kg N through vermicompost + 40 kg N through urea. N_3, which supplied 80 kg N through vermicompost, followed closely with 9.00 g. The lowest fresh weight (7.94 g) was seen with N_2 (60 kg N through vermicompost + 20 kg N through urea). The interaction between planting geometry and nitrogen sources showed significant variation, with the $S_1 \times N_1$ combination producing the highest fresh weight (10.50 g), followed by $S_3 \times N_3$ (9.55 g). The lowest fresh weight was observed in $S_3 \times N_2$ (6.89 g). **At 60 DAT**, the highest fresh weight was recorded in S_1-20 x 10 cm (26.70 g), followed by S_3-20 x 20 cm (22.98 g) and S_2-20 x 15 cm (22.00 g), with the lowest observed in S_4-30 x 10 cm (20.93 g). Among nitrogen sources, N_1 again produced the highest fresh weight (25.51 g), closely followed by N_3 (24.75 g). The lowest fresh weight was observed with N2 (19.47 g). The $S_1 \times N_1$ interaction produced the highest fresh weight (32.49 g), followed by $S_1 \times N_3$ (30.54 g). The lowest was recorded in $S_2 \times N_4$ (18.14 g). **At 90 DAT**, the highest fresh weight was again observed in S_1-20 x 10 cm (45.15 g), followed by S_3-20 x 20 cm (44.13 g) and S_2-20 x 15 cm (42.60 g), with the lowest in S_4-30 x 10 cm (41.50 g). Nitrogen treatments showed similar trends, with N_1 (45.00 g) and N_3 (44.60 g) producing the highest fresh weight, while N_2 (39.76 g) showed the lowest. The interaction effects showed significant variation, with $S_3 \times N_1$ producing the highest fresh weight (49.54 g), followed by $S_1 \times N_1$ (48.83 g). The lowest was recorded in $S_4 \times N_1$ (38.66 g). **At 120 DAT**, the highest fresh weight was recorded in S_1-20 x 10 cm (64.95 g), followed by S_3-20 x 20 cm (63.54 g) and S_2-20 x 15 cm (62.60 g), with the lowest in S4-30 x 10 cm (62.04 g). Among nitrogen sources, N_1 (64.41 g) and N_3 (64.21 g) recorded the highest fresh weight, while N_2 (61.14 g) had the lowest. The interaction effects showed significant variation, with $S_1 \times N_1$ producing the highest fresh weight (68.50 g), followed by $S_1 \times N_3$ (68.25 g). The lowest was observed in $S_4 \times N_1$ (60.01 g). **At harvest**, S_1-20 x 10 cm again recorded the highest fresh weight (64.34 g), followed by S_3-20 x 20 cm (62.07 g) and S_2-20 x 15 cm (61.77 g), with the lowest in S_4-30 x 10 cm (60.17 g). For nitrogen sources, N_1 (63.72 g) and N_3 (63.27 g) gave the highest fresh

weight, while N_2 (59.17 g) had the lowest. The $S_1 \times N_1$ combination again produced the highest fresh weight (70.06 g), followed by $S_3 \times N4$ (65.66 g) and $S_1 \times N_3$ (66.94 g). The lowest was observed in $S_4 \times N_2$ (57.79 g). The increased fresh weight observed in these treatments can be attributed to enhanced photosynthetic activity, leading to greater nutrient uptake and higher dry biomass accumulation throughout the plant's growth cycle. These findings are in line with similar studies by (Harisha *et al*., 2010) on garden cress and (Hemalatha *et al*., 2010) on Kalmegh, where the application of appropriate nitrogen doses was found to support improved growth and biomass production.

Table 2:- Effect of N sources, planting geometries, and their interactions on fresh weight (g plant^{-1}) at various growth stages in Kalmegh.

Treatments		30 DAT	60 DAT	90 DAT	120 DAT	At harvest
N Sources						
N_1	**40kg N by vermi +40 kg N by Urea**	9.13	25.51	45.00	64.41	63.72
N_2	**60kg N by vermi +20 kg N by Urea**	7.94	19.47	39.76	61.14	59.17
N_3	**80 kg N by Vermi**	9.00	24.75	44.60	64.21	63.27
N_4	**RDF**	8.41	22.86	44.02	63.37	62.18
S.Em ±		**0.18**	**0.85**	**1.01**	**0.99**	**0.85**
CD at 5%		**0.53**	**2.45**	**2.90**	**2.87**	**2.44**
Geometry						
S_1	**20 X 10 cm**	9.22	26.70	45.15	64.95	64.34
S_2	**20 X 15 cm**	8.32	22.00	42.60	62.60	61.77
S_3	**20 X 20 cm**	8.72	22.98	44.13	63.54	62.07
S_4	**30 X 10 cm**	8.21	20.93	41.50	62.04	60.17
S.Em ±		**0.18**	**0.85**	**1.01**	**0.99**	**0.85**
CD at 5%		**0.53**	**2.45**	**2.90**	**2.87**	**2.44**
Interaction S (Geometry) x N (Sources)						
$S_1 \times N_1$		10.50	32.49	48.83	68.50	70.06
$S_2 \times N_1$		9.01	24.16	42.95	63.96	62.62
$S_3 \times N_1$		9.27	26.54	49.54	65.17	64.17
$S_4 \times N_1$		7.72	18.87	38.66	60.01	58.01
$S_1 \times N_2$		8.09	18.91	38.72	60.19	58.63
$S_2 \times N_2$		8.31	19.47	39.39	60.66	58.68
$S_3 \times N_2$		6.89	17.70	38.35	59.24	56.25
$S_4 \times N_2$		8.47	21.81	42.60	64.46	63.13
$S_1 \times N_3$		9.35	30.54	48.73	68.25	66.94
$S_2 \times N_3$		8.66	26.22	45.37	64.34	62.22
$S_3 \times N_3$		9.55	19.91	40.60	61.52	62.20
$S_4 \times N_3$		8.42	22.33	43.70	62.73	61.73
$S_1 \times N_4$		8.94	24.84	44.32	62.86	61.71
$S_2 \times N_4$		7.30	18.14	42.67	61.46	63.55

$S_3 \times N_4$	9.17	27.77	48.04	68.23	65.66
$S_4 \times N_4$	8.23	20.69	41.04	60.95	57.79
S.Em ±	**0.36**	**1.69**	**2.01**	**1.99**	**1.69**
CD at 5%	**1.05**	**4.89**	**5.81**	**5.73**	**4.88**

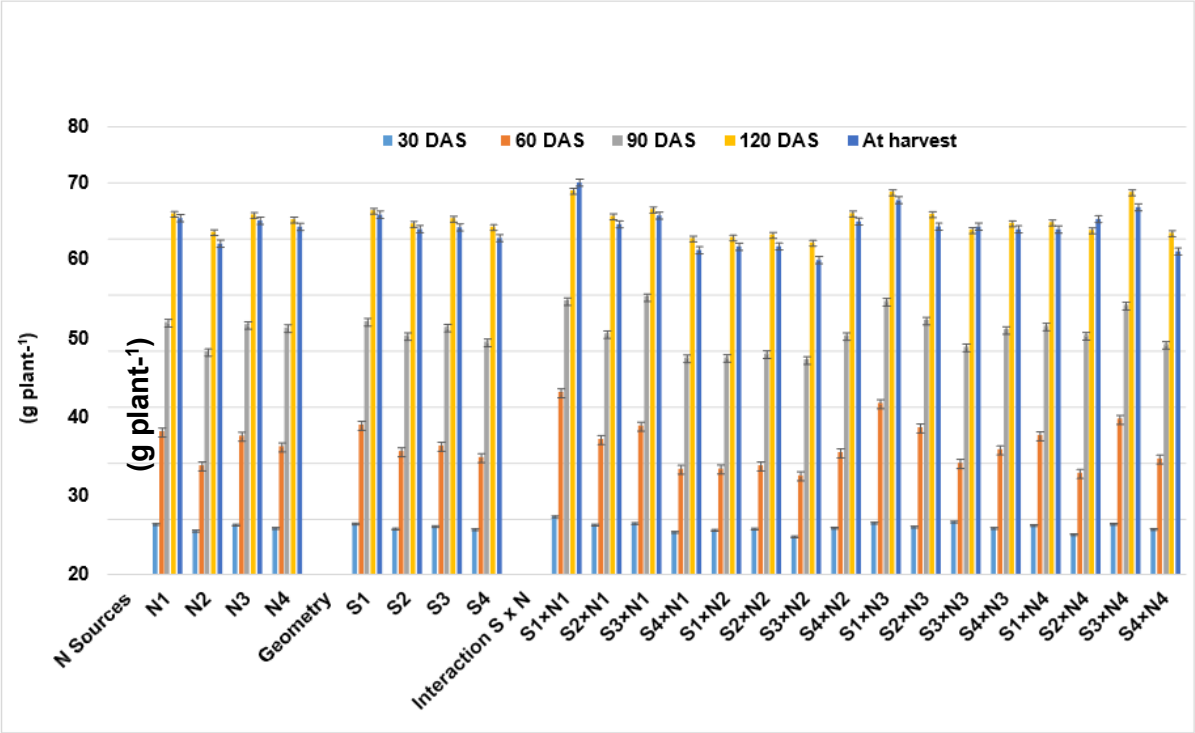

Fig.-2 Effect of nitrogen sources, planting geometries, and their interactions on fresh weight

Dry weight (g plant^{-1}) at 30, 60, 90, 120DAT and at harvest

The dry weight of Kalmegh plants was significantly influenced by nitrogen sources, planting geometries, and their interactions at various growth stages (30, 60, 90, 120 DAT, and at harvest), as presented in Table 3 and depicted in Fig. 3. **At 30 DAT**, the highest dry weight was recorded in S_1-20 x 10 cm (2.76 g), followed by S_3-20 x 20 cm (2.52 g) and S_2-20 x 15 cm (2.25 g). The lowest dry weight was observed in S_4-30 x 10 cm (1.96 g). For nitrogen sources, N_1 (40 kg N through vermicompost + 40 kg N through urea) resulted in the highest dry weight (2.68 g), followed by N_3 (80 kg N through vermicompost) at 2.64 g. The lowest dry weight (2.01 g) was observed with N_2 (60 kg N through vermicompost + 20 kg N through urea). The interaction between planting geometry and nitrogen sources showed significant variation, with the combination of $S_1 \times N_1$ producing the highest dry weight (3.49 g), followed by $S_3 \times N_3$ (3.03 g) and S1 × N3 (3.08 g). The lowest dry weight was recorded in $S_4 \times N_4$ (1.51 g). **At 60 DAT**, the highest dry weight was recorded in S_1-20 x 10 cm (6.92 g), followed by S_3-20 x 20 cm (6.02 g) and S_2-20 x 15 cm (5.70 g), with the lowest in S_4-30 x 10 cm (5.10 g). Among nitrogen sources, N_1 resulted in the highest dry weight (6.81 g), followed by N_3 at 6.35 g. The lowest was observed with N_2 (4.63 g). The interaction between planting geometry and nitrogen sources showed significant variation, with $S_1 \times N_1$ producing the highest dry weight (8.54 g), followed by $S_3 \times N_1$ (7.93 g) and $S_1 \times N_3$ (7.50 g). The lowest dry weight was observed in $S_3 \times N_2$ (3.86 g). **At 90 DAT**, S_1-20 x 10 cm again recorded the highest dry weight (22.98 g), followed by S_3-20 x 20 cm (21.92 g) and S_2-20 x 15 cm (20.62 g), with the lowest in S_4-30 x 10 cm (20.75 g). Nitrogen source N_1 resulted in the highest dry weight (23.06 g), followed by N_3 (21.95 g). The lowest was recorded with N_2 (20.28 g). The interaction between planting geometry and nitrogen sources showed significant variation, with the combination of $S_1 \times N_1$ producing the highest dry weight (28.68 g), followed by $S_3 \times N_1$ (23.67 g) and $S_3 \times N_3$ (22.78 g). The lowest was observed in $S_3 \times N_2$ (19.25 g). **At 120 DAT**, the highest dry weight was recorded in S_1-20 x 10 cm (41.70 g), followed by S_3-20 x 20 cm (40.00 g) and S_2-20 x 15 cm

(39.51 g), with the lowest in S_4-30 x 10 cm (39.01 g). For nitrogen sources, N_1 resulted in the highest dry weight (41.77 g), followed by N_3 (41.28 g). The lowest was observed with N_2 (37.27 g). The interaction effects showed that $S_1 \times N_1$ produced the highest dry weight (46.61 g), followed by $S_3 \times N_1$ (43.66 g) and $S_1 \times N_3$ (43.58 g). The lowest was recorded in $S_3 \times N_2$ (35.34 g). **At harvest**, S_1-20 x 10 cm recorded the highest dry weight (44.22 g), followed by S_3-20 x 20 cm (42.69 g) and S_2-20 x 15 cm (41.69 g), with the lowest in S_4-30 x 10 cm (41.10 g). Among nitrogen sources, N_1 (40 kg N through vermicompost + 40 kg N through urea) recorded the highest dry weight (44.17 g), followed by N_3 (43.87 g). The lowest dry weight (38.82 g) was observed with N_2 (60 kg N through vermicompost + 20 kg N through urea). The combination of $S_3 \times N_1$ produced the highest dry weight (48.07 g), followed by $S_1 \times N_1$ (47.79 g) and $S_3 \times N_4$ (47.42 g). The lowest dry weight was recorded in $S_3 \times N_2$ (36.25 g). The increased dry weight in these treatments likely contributed to higher productivity of Kalmegh, with factors such as fresh herbage yield per plant and per hectare playing a crucial role. These results align with findings from various studies (Husain and Kumar, 2024; Chand et al., 2011; Dakhane and Nandkarm *et al*., 2012; Kanjilal *et al*. 2002; Makwana *et al*., 2010; Ramesh *et al*., 2011; Sanjutha *et al*., 2006; Singh *et al*., 2006), which also reported that organic fertilizers significantly improved yield attributes and overall crop productivity.

Table 3: - Effect of N sources, planting geometries, and their interactions on dry weight (g plant^{-1}) at various growth stages in Kalmegh.

Treatments		30 DAT	60 DAT	90 DAT	120 DAT	At harvest
N Sources						
N_1	**40kg N by vermi+40 kg N by Urea**	2.68	6.81	23.06	41.77	44.17
N_2	**60 kg N by vermi+20 kg N by Urea**	2.01	4.63	20.28	37.27	38.82
N_3	**80 kg N by Vermi**	2.64	6.35	21.95	41.28	43.87
N_4	**RDF**	2.15	5.95	20.97	39.91	42.84
S.Em ±		**0.15**	**0.31**	**0.42**	**0.88**	**0.95**
CD at 5%		**0.44**	**0.89**	**1.21**	**2.54**	**2.74**
Geometry						
S_1	**20 X 10 cm**	2.76	6.92	22.98	41.70	44.22
S_2	**20 X 15 cm**	2.25	5.70	20.62	39.51	41.69
S_3	**20 X 20 cm**	2.52	6.02	21.92	40.00	42.69
S_4	**30 X 10 cm**	1.96	5.10	20.75	39.01	41.10
S.Em ±		**0.15**	**0.31**	**0.42**	**0.88**	**0.95**
CD at 5%		**0.44**	**0.89**	**1.21**	**2.54**	**2.74**
Interaction S (Geometry) x N (Sources)						
$S_1 \times N_1$		3.49	8.54	28.68	46.61	47.79
$S_2 \times N_1$		2.58	6.11	20.55	40.77	42.77
$S_3 \times N_1$		2.70	7.93	23.67	43.66	48.07
$S_4 \times N_1$		1.95	4.63	19.33	36.03	38.03
$S_1 \times N_2$		2.03	4.71	19.78	36.11	38.11
$S_2 \times N_2$		2.10	4.75	20.14	37.19	38.49
$S_3 \times N_2$		1.65	3.86	19.25	35.34	36.25
$S_4 \times N_2$		2.27	5.19	21.97	40.43	42.43
$S_1 \times N_3$		3.08	7.50	22.68	43.58	46.47

$S_2 \times N_3$	2.37	7.07	21.05	40.66	46.01
$S_3 \times N_3$	3.03	5.13	22.78	37.43	39.00
$S_4 \times N_3$	2.09	5.69	21.29	43.43	44.00
$S_1 \times N_4$	2.45	6.93	20.77	40.50	44.52
$S_2 \times N_4$	1.93	4.87	20.74	39.44	39.48
$S_3 \times N_4$	2.72	7.13	21.99	43.55	47.42
$S_4 \times N_4$	1.51	4.88	20.39	36.13	39.94
S.Em ±	**0.30**	**0.62**	**0.84**	**1.76**	**1.90**
CD at 5%	**0.88**	**1.78**	**2.41**	**5.08**	**5.47**

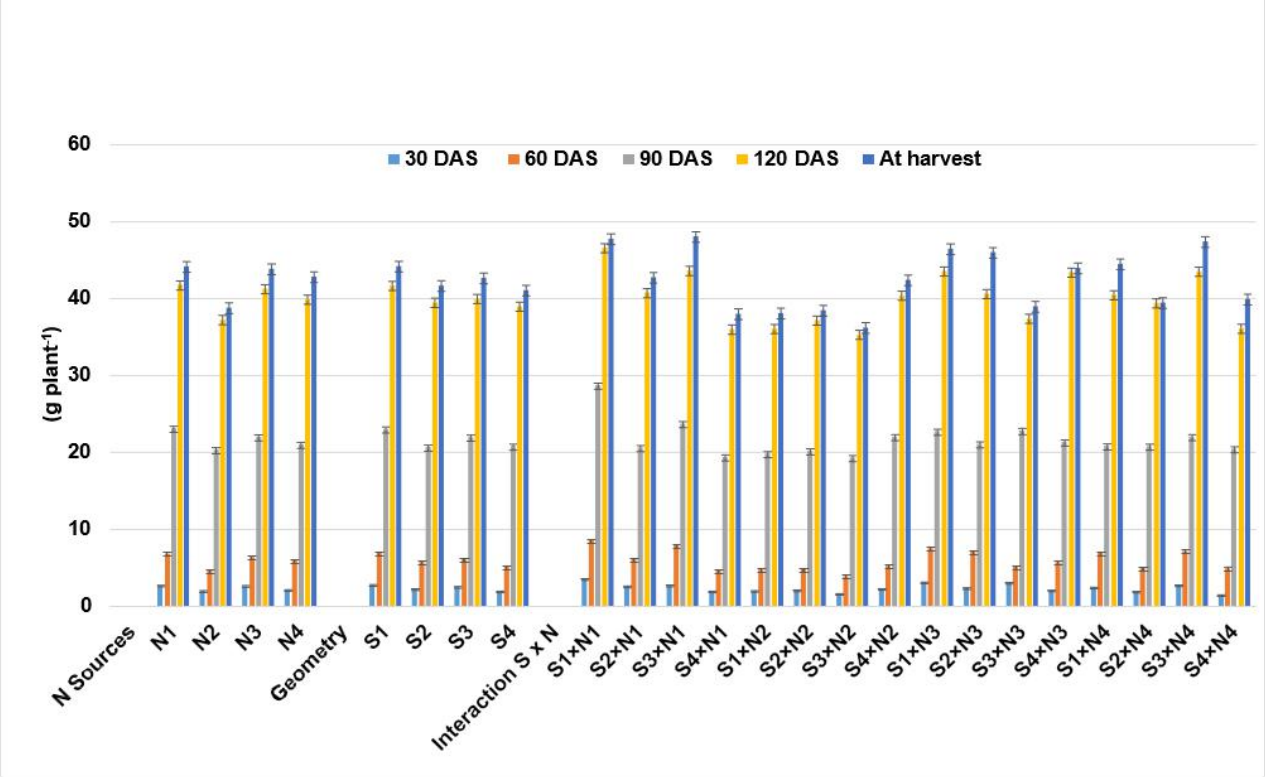

Fig 3:- Effect of nitrogen sources, planting geometries, and their interactions on dry weight (g plant^{-1}) at various growth stages in Kalmegh.

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International Journal of Environment, Agriculture and Biotechnology
Vol-10, Issue-3; May-Jun, 2025
Peer-Reviewed International Journal
Journal Home Page Available: https://ijeab.com/
Journal DOI: 10.22161/ijeab

Biology of major lepidopteran predators of Lac Insect

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Received: 10 Apr 2025; Received in revised form: 07 May 2025; Accepted: 13 May 2025; Available online: 18 May 2025

Abstract— *Investigations on "Biology of Major Lepidopteran Predators of Lac Insect, Kerria lacca (Kerr)" was carried out in the Department of Entomology, Rajasthan college of Agriculture, MPUAT, Udaipur, during 2021 with a view to record biological parameters viz., incubation period, larval and pupal period, pre-oviposition period, oviposition period, post-oviposition period, adult longevity, total life cycle, and fecundity and evaluate the bio-effecacy of organic treatments against major lepidopteran predators of lac insect. The incubation period of E. amabilis ranged from 3 to 5 days, the total larval-pupal period ranged from 22 to 38 days, the pre-oviposition period ranged from 4 to 6 days, the oviposition period lasted 5 to 7 days, and the post-oviposition period lasted between 3 and 6 days. The total life cycle of a female is 48-54 days. Adult male longevity ranged from 6 to 11 days. Female longevity ranged from 7 to 11 days, the Total life cycle of the female was 48-54 days, and the total lifespan of the male E. amabilis was 43 to 50 days. The average number of eggs laid by E. amabilis was 103.60. The Incubation period of P. pulverea ranged from 5 to 6 days. The total larval-pupal period ranged from 23 to 39 days, the pre-oviposition period ranged from 5 to 6 days, and the oviposition period ranged from 7 to 9 days. The post-oviposition period lasted between 5 and 8 days; male longevity ranged from 7 to 14 days. Female longevity ranged from 9 to 18 days, with a total life cycle of 49 to 59 days. The average number of eggs laid by P. pulverea was 92 eggs.*

Keywords— ***Lac insect, lepidopteran predators, biology, life cycle, organic treatments***

I. INTRODUCTION

Lac is a valuable natural resin secreted by the tiny scale insect *Kerria lacca* (Kerr), cultivated primarily on host plants such as *Butea monosperma* (palash), *Ziziphus mauritiana* (ber), and *Schleichera oleosa* (kusum) (Sharma *et al.*, 2006; Jaiswal *et al*., 2010). India is the leading global producer and exporter of lac, with the crop serving as an important source of livelihood for rural and tribal communities (Singh & Singh, 2011). Despite its economic significance, lac cultivation is hampered by several biotic stresses, chief among them being predation by insect pests (Thakur *et al.*, 2013). Lepidopteran predators pose a major threat to lac insects, particularly during the *Baisakhi* season (summer crop), which provides favorable environmental conditions for pest proliferation (Ghosh *et al.*, 2014). Two of the most damaging lepidopteran predators are *Eublemma amabilis* Moore and *Pseudohypatopa pulverea* Meyrick. These insects feed on lac cells or developing lac insects, causing significant damage to the crop and ultimately reducing resin yield (Meena *et al.*, 2017; Singh *et al.*, 2019). Understanding the biology, feeding behavior, and seasonal incidence of these predators is critical for devising timely and effective management strategies. In response to the limitations of chemical pesticides—such as environmental contamination, development of pest resistance, and negative effects on non-target organisms—organic treatments have emerged as a promising alternative (Verma & Karnatak, 2015). Organic pest control methods are gaining popularity for their eco-friendliness, sustainability,

and compatibility with traditional agricultural practices. However, scientific validation of the effectiveness of organic treatments against major lac predators, especially under field conditions during the *Baisakhi* season, remains limited (Patel *et al.*, 2020).

II. MATERIALS AND METHODS

The present investigation on the "Biology of Major Lepidopteran Predators of Lac Insect (Kerria lacca)," was carried out on the *Baisakhi* crop of *Rangeeni* strain on Ber during 2021-22 at lac insect field gene bank, Department of Entomology, Rajasthan Collage of Agriculture, Udaipur. The materials used and methodologies adopted are described as under:

1.1 Biology of major lepidopteran predators of lac insect

The biology of two major predators of lac insect viz. (*Eublemma amabilis* Moore and *Pseudohypatopa pulverea* Meyr) were studied on broodlac inoculated ten ber host plants, five plant for each predator at the Lac insect field gene bank, Department of Entomology, Rajasthan College of Agriculture, Udaipur. On these broodlac inoculated ber plants four branches on each plant were selected randomly and tagged after the proper initial settlement of crawlers and at middle part 50 cm of branch was covered with 60 mesh nylon net to avoid any external infestation of predators and parasitoids. To study the biology of major lepidopteran predators of lac insect the infested broodlac were collected from natural host and were kept in rearing cages (30cm X 30cm X 40cm) for the emergence of predators. The emerged moths of *E. amabilis* and *P. pulverea* were collected daily from the open end of the cages fitted with glass tubes. The five pairs of moths for each predator were kept in egg laying chamber for mating and to lay eggs. The newly hatched larvae thus collected were released inside the nylon net on the tagged branches having live lac cells and were regularly observed till the emergence of the adults. The larval-pupal duration (in days) was recorded after hatching till the emergence of adults from lac encrustations inside the nylon mesh on tagged branches for each predator, the moths emerged inside the nylon mesh were collected gently by opening the covering from one end, brought to the laboratory and kept in pairs (male and female) for each predator in different glass jars provided with 10% honey solution soaked cotton wicks in halves of small petri plates to record the duration (in days) for the survival of male, female and to record the fecundity of female for each predator.

1.1.1 Observation

i. **Incubation period:** The time (in days) taken by the eggs to hatch was recorded. The hatching of eggs was determined by the change in colour of the eggs.
ii. **Larval-pupal period:** Larval-pupal period (in days) within the lac cells were recorded by observing the number of days taken by larvae to complete its larval-pupal period and the number of days were recorded till the emergence of the adult.
iii. **Pre-oviposition period of female:** The duration in days from emergence to initiation of egg laying was recorded as pre-oviposition period of females.
iv. **Oviposition period of female:** The duration in days from the initiation of egg laying by female to the cease of egg laying was recorded as oviposition period of females.
v. **Post-oviposition period:** The duration (in days) after the cease to oviposition till the death of adult female was recorded.
vi. **Adult longevity:** The longevity of male and female adults (in days) after the emergence up to their death was recorded.
vii. **Life cycle completed (days):** Single generation time period from egg to deathwas calculated.
viii. **Fecundity:** The total number of eggs laid by each adult female during the life span of females was recorded.

Statistical analysis:-

The data recorded for efficacy of different treatments were statistically analyzed using standard procedure for analysis of variance (ANOVA) of CRD in order to test the significance of experimental. The CD for treatments was also worked out. Survival percentage of lac insect was worked out using the formula.

$$\text{Survival percentage} = \frac{\text{No.of live cells/cm}^2}{\text{Total no.of cells/cm}^2} \text{ x } 100$$

III. RESULTS AND DISCUSSION

Biology of major lepidopteran predators of lac insect

The experiment to study the biology of major lepidopteran predator of lac i.e. *E. amabilis* Moore and *P. pulverea* in terms of incubation period, larval and pupal period, pre-oviposition period, oviposition period, post-oviposition period, adult longevity, total life cycle and fecundity was carried out under maintained laboratory conditions. The observation recorded on various parameters of biology of two predators are presented in Table 1.1

Incubation period (days)

The time (in days) taken by the eggs of the two lepidopteran predators to hatch was recorded by regular observation on the colour of eggs. The observations of incubation period recorded for the *E. amabilis* ranged from 3 to 5 days

whereas, it ranged from 5 to 6 days for *P. pulverea*. The mean incubation period of 4.60 and 5.20 days was recorded for *E.* amabilis and *P. pulverea*, respectively during the experimentation.

Total larval-pupal period (days)

Larval-pupal period (in days) within the lac cells were recorded by observing the number of days taken by larvae to complete its larval-pupal period and the number of days were recorded till the emergence of the adult. The total larval-pupal period ranged from 22 to 38 days with the mean larval-pupal period of 25.88 days for *E. amabilis* and it ranged from 23 to 39 days with the mean larval period of 26.88 days for *P. pulverea*.

Pre-oviposition period (days)

The pre-oviposition period for the *E. amabilis* ranged from 4 to 6 days whereas, it ranged from 5 to 6 days for *P. pulverea*. The mean pre-oviposition period of 4.6 and 5.6 days was recorded for *E. amabilis* and *P. pulverea*, respectively during the experimentation.

Oviposition period (days)

The oviposition period for the *E. amabilis* ranged from 5 to 7 days whereas, it ranged from 7 to 9 days for *P. pulverea*. The mean oviposition period of 5.8 and 8.6 days was recorded for *E. amabilis* and *P. pulverea*, respectively during the experimentation.

Post-oviposition period (days)

The post-oviposition period for the *E. amabilis* ranged from 3 to 6 days whereas, it ranged from 5 to 8 days for *P. pulverea*. The mean post-oviposition period of 4.8 and 6.8 days was recorded for *E. amabilis* and *P. pulverea*, respectively during the experimentation.

Adult longevity period (Days)

Male The male longevity of *E. amabilis* ranged from 6 to 11 days with an average life period of 8.20 days when reared under laboratory conditions. In case of *P. pulverea*, the male longevity ranged from 7 to 14 days with an average life period of 11 days. Female The range of female longevity recorded was 7 to 11 days and 9 to 18 days for *E. amabilis* and *P. pulverea*, respectively. The average female longevity of 11.80 days was recorded for *E. amabilis* and 14 days for *P. pulverea* during the experiment.

Total life cycle (days)

Male The total life cycle of male of *E. amabilis* reared on lac ranged from 43 to 50 days with the average life span of 45 days under laboratory conditions. While, total life cycle of male of *P. pulverea* reared on lac ranged from 42 to 51 days with the average life span of 45.80 days. Female The total life cycle of female of *E. amabilis* reared on lac ranged from 43 to 50 days with the average life span of 45 days under laboratory conditions. While, total life cycle of female of *P. pulverea* reared on lac ranged from 49 to 59 days with an average life span of 53-40 days.

Fecundity (no. of eggs/female)

The mean number of eggs laid by single female *E. amabilis* and *P. pulverea* recorded was 103.60 eggs and 92 eggs, respectively. The range of egg laid by female *E. amabilis* was 90 to 110 eggs, whereas, it ranged from 80 to 105 eggs in case of *P. pulverea*.

IV. DISCUSSION

The lac production faces significant losses due to predation of lac insect by an array of predators. A total of 11 species of associated fauna i.e. predators, primary parasites and hyper parasites have been recorded on lac insect under 8 different families of 3 orders from different locations; of these, 8 belong to Hymenopetra, 2 to Lepidoptera, and 1 to Neuroptera. The predator species are represented by *Eublemma amabilis* Moore, *Pseudohypatopa pulverea* Meyr, and *Chrysopa zastrowi* (Esben Petersen) primary parasites of lac insect by *Tachardiaephagus tachardiae* Howard, *Aprostocetus pupureus* Cameron, *Parechthrodryinus clavicornis* Mashhood alam, *Erencyrtus dewitzi* Mahdihassan and hyper parasites *Apanteles fakhrulhajiae* Mahd, *Eupelmus tachardiae* Howard, *Bracon greeni* Ashmead, *Brachymeria tachardiae* Cam. Further analysis of the data revealed that 27.27 per cent of the genera as well as species belong to family Encyrtidae, 18.18 per cent to Braconidae and 9.09 per cent to each, Eupelmidae, Chalcididae, Noctuidae, Blastobasidae, Chrysopidae, and Eulophidae (Meena *et al.* 2018). Therefore, the study of biology of the major predator is essential to understand the trophic interactions of these associated lac fauna. The observations recorded from experiment to study the biology of major lepidopteran predator of lac i.e. *E. amabilis* and *P. pulverea* Meyr under laboratory conditions showed that the duration of complete life cycle of *E. ambilis* and *P. pulverea* ranged from 43-50 days and 42-51 days, respectively. The mean fecundity of *E. ambilis* was more i.e 103.60 eggs as compared to *P. pulverea* with 92.00 eggs. The mean incubation period, larval-pupal period of *E. ambilis* ranged from 22-38 days while it ranged from 23-39 days for *P. pulverea*. The results of present findings are in the conformity with the results of Mishra *et al.* (1930) who studied bionomics of the Noctuid, *E. amabilis* and reported that egg stage lasts from 1 to 10 days, the larval period from 16 to 128 days and the pupal period from 3 to 20 days and these stages varied according to the season. From November to February, the larvae are largely inactive.

Table 1.1: Different parameters of biology of lepidopteran lac predator *Eublemma amabilis* Moore during *Baisakhi* season 2021-22

S. No.	Life Stages	Mean	Range
1.	Incubation period (days)	5.20±0.84	5-6
2.	Total larval-Pupal period (days)	26.88±2.92	23-39
3.	Pupal period (days)	10.20±1.92	8-13
4.	Pre-oviposition period (days)	5.60±0.55	5-6
5.	Oviposition period (days)	8.60±1.14	7-9
6.	Post-oviposition period (days)	6.80±1.30	5-8
7.	Female adult longevity (days)	14.00±4.30	9-18
8.	Male adult longevity (days)	11.00±2.74	7-14
9.	Total life cycle of female (days)	53.40±4.16	49-59
10.	Total life cycle of male (days)	45.80±3.70	42-51
11.	Fecundity of female (No. of eggs)	92.00±10.93	80-105

1.2 Different parameters of biology of the lepidopteran lac predator *Pseudohypatopa pulverea* during *Baisakhi* season 2021-22

S. No.	**Life Stages**	**Mean**	**Range**
1.	Incubation period (days)	4.60±1.14	3-5
2.	Total larval- Pupal period (days)	25.88±1.92	22-38
3.	Pre-oviposition period (days)	4.60±0.89	4-6
4.	Oviposition period (days)	5.80±0.84	5-7
5.	Post-oviposition period (days)	4.80±1.30	3-6
6.	Female adult longevity (days)	11.80±2.95	7-14
7.	Male adult longevity (days)	8.20±1.92	6-11
8.	Total life cycle of female (days)	52.20±2.49	48-54
9.	Total life cycle of male (days)	45.00±3.81	43-50
10.	Fecundity of female (No. of eggs)	103.60±7.92	90-110

V. CONCLUSION

The study on the biology of two major lepidopteran predators of the lac insect, *Eublemma amabilis* Moore and *Pseudohypatopa pulverea*, revealed notable differences in their developmental and reproductive parameters under laboratory conditions. *E. amabilis* exhibited a slightly shorter incubation, larval-pupal, and total life cycle duration compared to *P. pulverea*. It also showed a higher fecundity rate, averaging 103.6 eggs per female, as against 92 eggs in *P. pulverea*. Additionally, the adult longevity and oviposition periods were generally longer in *P. pulverea*. These findings contribute valuable insights into the life history traits of these predators, which are crucial for understanding their potential impact on lac cultivation and for developing integrated pest management strategies.

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International Journal of Environment, Agriculture and Biotechnology
Vol-10, Issue-3; May-Jun, 2025
Peer-Reviewed International Journal
Journal Home Page Available: https://ijeab.com/
Journal DOI: 10.22161/ijeab

Sustainable Processing and Commercialization of Underutilized Fruits in North East India

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Received: 13 Apr 2025; Received in revised form: 11 May 2025; Accepted: 17 May 2025; Available online: 22 May 2025

Abstract— *The Eastern Himalayan region of India are known for its diverse nature of soil, climate, topography and also rich diversity of less-known, indigenous, underutilized and ethno-medicinally important fruit crops. The underutilized or neglected fruit crops represent an enormous wealth of agrobiodiversity growing wildly in the forest and in almost every homestead and backyard without much care and attention. These crops have great potential for contributing to food security and nutrition, health (nutritional/medicinal), income generation, environmental services and combating the hidden hunger caused by micronutrient deficiencies. Though having many incredible potential, they are less or poorly documented as they have lesser demand in the market, neither they are grown commercially nor traded, lesser known to people about its cultivation, distribution and its value. Through social media and advancement of technology, some tribals have come forward to promote their ways of consuming and preserving by becoming an entrepreneur and making their products commercially available online and offline. Commercialized value-added products of some underutilized fruits from different northeast India were documented here. The commercialization of underutilized fruits in Northeast India holds significant potential for economic, nutritional, and social impacts and also holds significant potential for future research and development. It is high time that the communities, researchers and the entrepreneurs all work together to make these minor fruit crops a commercially viable fruit crop of future.*

Keywords— ***Commercialization, Eco-sustainability, Eastern Himalayan region, Underutilized.***

I. INTRODUCTION

The Eastern Himalayan region of India consist of 8 states namely Assam, Tripura, Arunachal Pradesh, Sikkim, Meghalaya, Manipur, Nagaland, and Mizoram occupying more than one-third of the country's total diversity where total area occupies 7.7% of India's total geographic areas supporting 50% of the biodiversity in the country, of which 31.58% is endemic (Rai et al., 2005; Mao and Hynniewta, 2000). The region are known for its diverse nature of soil, climate, topography and also rich diversity of less-known, indigenous, underutilized and ethno-medicinally important fruit crops which are being used by the local inhabitants in rural areas. The underutilized or neglected fruit crops represent an enormous wealth of agrobiodiversity growing wildly in the forest and in almost every homestead and backyard without much care and attention. These crops have great potential for contributing to food security and nutrition, health (nutritional/medicinal), income generation, environmental services and combating the hidden hunger caused by micronutrient deficiencies. Though having many incredible potential, they are less or poorly documented as they have lesser demand in the market, neither they are grown commercially nor traded, lesser known to people about its cultivation, distribution and its value. The fact and

figures of wild edible fruit tree species in different states of the North east region are limited and scattered (Table 1)

Table 1: Underutilized fruit crops grown in NEH Region

State	No. of species reported
Arunachal Pradesh	14 in Changlang Dist. (Sarma, 2001)
Assam	147 (Patiri and Borah, 2007)
Manipur	23 from Senapati district (Pfoze *et al.*, 2011)
Meghalaya	151 (Jeeva, 2009)
Mizoram	85 (Kar *et al.*, 2013)
Nagaland	86 (Pfoze *et al.*, 2014)
Sikkim	126 (Sundriyal *et al.*, 1998; Sundriyal and Sundriyal, 2003)
Tripura	86 (Majumder and Dutta, 2009)

But these underutilized fruits are packed with rich vitamins, minerals, antioxidant properties and serve as protective food as they have medicinal properties. They also have good flavour, colour, juice content which is an excellent ingredients to turn into value added products. These underutilized fruits are yet to be commercially utilized to their potential and their importance from the abundantly available resources is limited to people residing in rural areas. The only remedy for making the fruits commercially available for all people and also to upgrade the economic and nutritional security for tribal people is to educate the villagers about the nutritional quality of underutilized fruits and its techniques and benefits for making value added products making the fruits more useful, digestive, tasteful and convenient products.

II. VALUE ADDED PRODUCTS

Processing of underutilized fruits and converting into value added products is requisite as it gives higher value added product for human consumption, better employment opportunities to the people especially during off-season in the agricultural sectors, ensures fair returns to the growers improving their economic condition, helps in better utilization of fruits and also utilize the surplus during the off-season. In addition to real value to a food, purity, authenticity, health claims and sustainability are also key ingredients which needs to be maintained. The tribal people of Northeast region mainly processed the underutilized fruits for their consumption only and during the off season. Several states of Northeast have their own specialty of preserving and consuming the indigenous fruits though they lack the knowledge, techniques of processing and importance of underutilized fruits. Through social media and advancement of technology, some tribals have come forward to promote their ways of consuming and preserving by becoming an entrepreneur and making their products commercially available online and offline. People in the region are increasingly recognizing the potential for processing and adding value to underutilized fruits by transforming them into a variety of products such as jams, sauces, jellies, soups, candies, confectionery, pickles, fruit drinks, and dried goods.

III. COMMERCIALIZED VALUE-ADDED PRODUCTS OF SOME UNDERUTILIZED FRUITS FROM DIFFERENT NORTHEAST INDIA

1. Rhus chinensis Mill

Rhus chinensis Mill, belongs to Anacardiaceae family is commonly known as Nutgall tree or Chinese sumac (Fig.1 (a)), Heimang in Manipur, Sohmluhi in Khasi Hills and Sohsama in Jaintia Hills. It is one of the underutilized wild indigenous fruit widely found growing abundantly in North eastern parts of India, China, Japan, Korea and South Asian countries. It plays a major role in supplementing the diet of the local inhabitants of Manipur. The tiny seeded fruit (Fig.1) is a red fleshy drupe, occurring in cluster of galls with red glandular hairs on the fruit wall and acidic in taste. The fruits are rich sources of several antioxidants such as tannin, gallic acid and minerals. Traditionally, the local medical practitioners use the ripe fruits in the treatment of kidney stones and urinary complaints, intestinal worms, dyspepsia, anti-diarrhoea, stomach ulcer, and gastrointestinal disturbances.


Fig. 1(a): Rhus chinensis Mill

Since the fruit is consumed throughout Manipur, the fruit has been developed to produce processed food such as ready to eat Heimang powder, Heimang tea, and Heimang candy as given below with its process flowchart and picture of processed products in fig. 1 (b) - (d).

1.1 Heimang powder

Heimang
↓
Drying heimang under
↓
Grinding to
↓
Mixing heimang powder, sugar, salt, and chilli
↓
Packed in plastic pouches and

Fig. 1(b): Heimang Powder

1.2 Heimang Tea

Process Flochart for Heimang Tea

Heimang fruits
↓
Drying heimang under sun
↓
Grinding the fruits to powder
↓
Mixing of heimang powder and tea leave powder.
↓
Fill the mixture in tea bags.
↓
Packed and store.

Fig. 1 (c): Heimang Tea

1.3 Heimang Candy

Process Flowchart for Heimang Candy

Heimang fruits

↓

Clean and graded.

↓

Drying of fruits under sun

↓

Addition of melted jaggery to dried heimang

↓

Mixing of both ingredients

↓

Molded into small balls.

↓

Coated with small coarse sugar.

↓

Packed and stored.

Fig. 1(d): Heimang Candy

2. Wild Apple (*Docynia Indica*)

This fruit belongs to the family Rosaceae, and commonly found in Sikkim and Meghalaya. Locally called as Soh-phoh in Khasi (Meghalaya) and Heitup in Manipur. The fruits are round (Fig. 2), pear shaped and pale green colour when ripe. The taste of the fruit in the foot hill tracts ranged from medium sweetness to acidic and astringent varies with genotypes. The fully ripe fruit is eaten as fresh, while the half ripe ones are consumed as fresh and processed into pickles, salted dried or candied. This fruit product consists of polyphenol compounds, especially flavonoids and alkaloids which reduces the blood glucose concentration, and in turn have anti-obese effect in mice. The Manipur people commercialized the fruits processing them into pickle Fig. 2 (a), salted dried Fig. 2 (b) and candied. Fig. 2 (c).

Fig. 2: Wild Apple

Fig. 2 (a): Wild Apple Pickle

Fig. 2 (b): Salted dried Wild Apple

Fig. 2 (c): Candied Wild Apple

3. Passion fruit (*Passiflora edulis Sims*)

Mizoram, Manipur, Nagaland, and Sikkim states of Northeastern region of India, holds great potential for Passion fruit (*Passiflora edulis Sims*). In Manipur, it is commonly known as Shitaphal, while in Meghalaya, it is called Soh-brab. Both yellow and purple varieties are cultivated in various districts of Manipur, including Chandel, Churachandpur, Ukhrul, Thoubal, Bishnupur, and Tamenglong. There are two varieties of passion fruit, purple and yellow colour. Generally distinguished by reddish, pinkish, or purplish coloration in its stems, leaves, and tendrils. The purple passion fruit (P. edulis) is a woody, robust, perennial vine. Its fruit is ovoid and turns deep purple when fully ripe while the yellow variety (P. edulis f. flavicarpa) has a vine similar to that of the purple variety but is more vigorous in growth. Passion fruit is a rich source of vitamin A and C with high juice content. It can be eaten raw or processed to enhance the flavor of ice cream, jams, and refreshing beverages like squash. A pictorial representation of the fruit, a process flowchart for preparing passion fruit squash, and the commercially produced product from Manipur are shown below in Figures 3 and 3(a).

Process flowchart of Passion fruit squash

Passion fruits
↓
Peel and collect the pulp with seeds.
↓
Extract juice and remove the fiber and seed by filtration using muslin cloth.
↓
Add sugar, water, and citric acid.
↓
Boils the ingredients until sugar dissolve.
↓
Add preservative for flavor and colour.
↓
Fill the squash in sterilized bottle.
↓
Sealed the cap.
↓
Stored in cool & dry place.

Fig. 3:Passion fruit

*Fig. 3(a): Passion fruit squash***.**

4. Wild olive (*Elaegnus, spp*)

Wild olive (Fig. 4) belonging to family Elaeagnaceae consists of two species such as *E. latifolia* and *E. pyriformis*, they are commonly known as Sohshang in Khasi Hills, Slangi in Jaintia Hills and Mirica tenga in Assamese. It is one of the very popular and important minor fruit indigenous to Northeast India mainly in Sibsagar (Dikho valley of Assam), Naga hills (Nagaland), Khasi, Jaintia hills of Meghalaya and Sikkim. The fruits of E. latifolia are oblong with dark pink in colour at full ripew whereas, fruits of E. pyrifomis are pyriform with slightly pointed at both ends. They are very perishable with shelf-life of only 3–5 days at room temperature (20-24 °C). The fruits are very rich source of vitamins and minerals, especially in vitamins A, C and E, flavonoids, other bio-active compounds, good source of essential fatty acids, which is fairly unusual for a fruit and are capable of reducing the incidence of cancer and also as a means of halting or reversing the growth of cancers. All parts of the fruits are edible including seed, at all stages of fruit growth. They are consumed raw with salt or used in pickle preparation, jam and refreshing drink by the tribes. The pickle shown in Fig. 4 (a) are commercially sold online and available for all people.

Fig. 4: Wild olive

Fig. 4 (a): Wild olive pickle

5. Elephant Apple (*Dillenia Indica L*)

Elephant apple belongs to family Dilleniaceae and locally called as Otenga (Assam) found in Assam, Meghalaya and other states of North Eastern region. This fruit (Fig. 5) originated from Indonesia and is a spreading tree arranged with beautiful white fragrant flowers, serrated or toothed leaves and globose fruits with small brown seeds. The greenish-yellow fruit which have a thick protective covering is edible. The juicy pulp is very acidic and the unripe fruits are used in cooking to make pickle and chutney. The elephant apple pickle shown in Fig. 5 (a) was commercial available online.

Fig. 5: Elephant Apple

Fig. 5 (a): Elephant Apple Pickle

6. Prunus Nepalensis

This fruit (Fig.6) belongs to Rosaceae family, commonly known as Sohiong in Khasi (Meghalaya) is naturally distributed in East Khasi Hills, West Khasi hill and Jaintia hills district of Meghalaya between 1500 and 2000 m altitude. It is an important indigenous nutritionally rich lesser known fruit of temperate area. The fruit are drupe, smooth fleshy round in shape, dark purple in colour at full ripe and green to pinkish colour in immature stage and the stone is hard. There are two types of Sohiong fruits based on size, viz., big and small fruit size, when mature they are bigger in size and purplish or blackish brown. This fruits eaten raw and used for processing into value added products such as wine, squash, fruit juice and jam making. The Sohiong squash (Fig. 6 (a)) and jam (Fig. 6 (b)) are commercially sold online and made available for all.

Fig. 6: Sohiong Fruits

Fig. 6 (a) Sohiong Squash

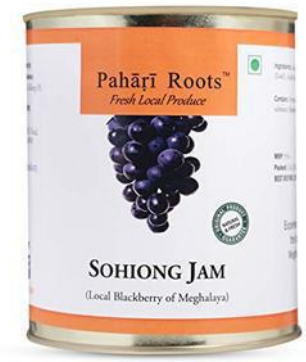

Fig. 6 (b): Sohiong Jam

7. Myrica farquhariana Wall

This fruit crop belongs to family Myricaceae which is commonly known as Box Myrtle (Fig. 7) as general, Soh-phie-nam in Khasi and Saphai in Jaintia Hills. The fruits are very common among the 'Hynniewtrep' and is the state fruit of Uttarakhand. The fruit have many medicinal properties and the edible part of the fruit pulp consist of 75% of the fruit and are eaten fresh at all stages of its growth. It is one of the tastiest and preferred wild fruits of the community. It has several commercial importance as the fruits are used for making refreshing drink and pickle (Fig. 7 (a)) giving attractive sparkling red colour.

Fig. 7: Box Myrtle

Fig. 7 (a): Box Myrtle pickle

8. Assam Lemon

The most common and abundant citrus fruit found in North East state of Assam is the Assam Lemon (Fig. 8) locally known as 'Kazi Nemu'. It is found growing in the backyards of almost every Assamese household without productive measures taken for it. The lemon is generally oval and green in color with a standard size of 85gm to 125gm which is comparatively larger and

contain more juice than rough lemon. The Assam Lemon is the proud beholder of a number of other useful characteristics like aroma, medicinal value, so on so forth. The juice content per lemon is 36% to 44% of the total volume of the fruit. This citrus fruit is grown all-round the year and is mainly use in pickle (Fig. 8 (a)) for their own households and sold commercially online.

Fig. 8: Assam lemon Pickle

Fig. 8 (a): Assam lemon pickle

9. Carambola (*Averrhoea Carambola L*)

Carambola is locally known as 'Soh Pyrshong' in Khasi (Meghalaya) and Heinoujom in Manipur belonging to family Oxalidaceae. It is grown all over northeastern region of India and known as star fruit as the fruit are elongate and angular which is composed of 5 carpels giving a star-shaped cross section resembling a star. The skin is thin, pale to deep yellow and smooth with a waxy cuticle while the flesh is pale yellow-to- golden yellow, translucent, crispy, very juicy, and fibreless. The fruits are more or less oxalic acid in odour and very sour to mildly sweet in flavour. Ripen fruits (Fig. 9) are eaten raw as well as produced processed products like squash, candy (Fig. 9 (a)), pickle (Fig. 9 (b)) and refreshing drink.

Fig. 9: Carambola

Fig.9 (a): Carambola candy

Fig. 9(b): Carambola pickle

10. Ceylon olive (*Elaeocarpus serratus*)

Ceylon olive (*Elaeocarpus serratus* L.) belongs to family Elaeocarpaceae is one of the under-utilised edible fruit tree. The fruit pulp of *E. serratus* is rich in minerals, fibre, vitamins, and phenolic compounds, most of which are antioxidants with medicinal

properties. Fresh and ripened fruit (Fig. 10) are edible and used for preparation of value-added products such as squash, jam, candy (Fig. 10 (a)) and pickles.

Fig. 10: Ceylon olive

Fig. 10 (a): Ceylon olive candy

IV. IMPACT AND APPLICATIONS: POTENTIAL ECONOMIC, NUTRITIONAL, AND SOCIAL IMPACTS OF COMMERCIALIZING UNDERUTILIZED FRUITS

The commercialization of underutilized fruits in Northeast India holds significant potential for economic, nutritional, and social impacts. This section discusses these potential impacts in detail, supported by relevant references.

1. Economic Impact

Commercializing underutilized fruits can lead to substantial economic benefits for local communities. By developing value-added products such as jams, jellies, candies, pickles, and beverages, local farmers and entrepreneurs can access new markets and improve their income levels. The processing of these fruits can create employment opportunities, especially for women and youth, thereby reducing migration to urban areas in search of jobs. This can also help in mitigating the problem of underemployment during the off-season in the agricultural sector. The increased market demand for these products can stimulate local economies and encourage the development of small and medium-sized enterprises (SMEs). As these fruits are indigenous to the region, they can be marketed as unique and exotic products, attracting both domestic and international consumers. The establishment of supply chains for these fruits can also promote infrastructural development, such as better transportation and storage facilities. For example, the commercial production of products like Heimang powder, Heimang tea, and passion fruit squash in Manipur has demonstrated the viability and profitability of such ventures (Koley & Kaur, 2019; Mahapatra et al., 2012).

2. Nutritional Impact

Underutilized fruits are often rich in essential nutrients, vitamins, minerals, and antioxidants, which are crucial for combating malnutrition and micronutrient deficiencies. These fruits can serve as a significant source of nutrition for local populations, improving overall health outcomes. For instance, fruits like wild olive, elephant apple, and Ceylon olive are high in vitamins A, C, and E, and flavonoids, which have numerous health benefits, including boosting the immune system and reducing the risk of chronic diseases (Arora & Nayar, 1984; De Caluwe et al., 2010).

Integrating these fruits into the diet can help address "hidden hunger," a form of malnutrition caused by a lack of essential micronutrients. This is particularly important in rural and tribal areas where access to a diverse diet is limited. The promotion of these fruits can also encourage dietary diversity, leading to better health outcomes.

3. Social Impact

The commercialization of underutilized fruits can have profound social impacts, particularly in empowering women and marginalized communities. Women often play a key role in the collection, processing, and marketing of these fruits. By formalizing and commercializing these activities, women can gain financial independence and contribute to their household income, thereby improving their social status and reducing gender inequalities (Mishra et al., 2015; Uprety et al., 2012).

Additionally, preserving and promoting the use of indigenous fruits can help maintain cultural Sheritage and traditional knowledge associated with these crops. This can foster a sense of pride and identity among local communities, encouraging the younger generation to value and continue these traditions.

The collaboration between researchers, entrepreneurs, and local communities can also strengthen social cohesion and foster a spirit of innovation and entrepreneurship. For example, initiatives to produce and market wild apple pickle, salted dried wild apple, and candied wild apple in Meghalaya and Sikkim have brought communities together,

creating a sense of shared purpose and mutual support (Roy & Rao, 2006; Jamir & Takatemjen, 2012).

Case Studies and Examples

1. **Rhus chinensis Mill (Heimang)**

- **Economic Impact**: Development of Heimang powder, tea, and candy has created a niche market in Manipur, boosting local incomes.
- **Nutritional Impact**: Rich in antioxidants like tannin and gallic acid, these products help in addressing health issues such as kidney stones and gastrointestinal disturbances.
- **Social Impact**: Traditional knowledge of Heimang's medicinal properties is preserved and propagated, enhancing community pride.

2. **Wild Apple (Docynia Indica)**

- **Economic Impact**: Wild Apple products like pickles, salted dried fruits, and candies have commercial potential in Sikkim and Meghalaya.
- **Nutritional Impact**: High polyphenol content contributes to anti-obesity and blood glucose regulation.
- **Social Impact**: Commercialization supports local farmers and entrepreneurs, promoting sustainable livelihoods.

3. **Passion Fruit (Passiflora edulis Sims)**

- **Economic Impact**: Processing into juice, jams, and squashes has opened new market avenues in Mizoram, Manipur, Nagaland, and Sikkim.
- **Nutritional Impact**: Excellent source of vitamins A and C, beneficial for immune health and skin care.
- **Social Impact**: Encourages the cultivation of passion fruit, involving community members in value-added production.

4. **Wild Olive (Elaegnus spp)**

- **Economic Impact**: Pickle production has provided a stable income for communities in Assam and Nagaland.
- **Nutritional Impact**: High in vitamins A, C, E, and essential fatty acids, contributing to cancer prevention and overall health.
- **Social Impact**: Enhances food security by making nutritious food available throughout the year.

5. **Elephant Apple (Dillenia Indica L)**

- **Economic Impact**: Commercially available pickles have generated additional income for Assamese households.
- **Nutritional Impact**: Acidic pulp is used in traditional medicine, aiding in digestion and overall health.
- **Social Impact**: Promotes the use of traditional fruits in modern cuisine, preserving culinary heritage.

6. **Prunus Nepalensis (Sohiong)**

- **Economic Impact**: Sohiong products like squash and jam are commercially viable, boosting local economies in Meghalaya.
- **Nutritional Impact**: Rich in vitamins and antioxidants, supporting overall health and well-being.
- **Social Impact**: Encourages sustainable harvesting and processing practices, benefiting the environment and community.

7. **Assam Lemon**

- **Economic Impact**: Pickle production has become a lucrative business in Assam, supporting many households.
- **Nutritional Impact**: High juice content rich in vitamin C, enhancing immunity.
- **Social Impact**: Promotes the cultivation of indigenous crops, preserving agricultural diversity.

8. **Carambola (Averrhoa Carambola L)**

- **Economic Impact**: Processing into candy and pickle has created new market opportunities.
- **Nutritional Impact**: Provides essential vitamins and minerals, supporting health.
- **Social Impact**: Encourages the use of traditional fruits in contemporary food products.

9. **Ceylon Olive (Elaeocarpus serratus)**

- **Economic Impact**: Value-added products like squash and candy have commercial potential.
- **Nutritional Impact**: Rich in antioxidants and bioactive compounds, beneficial for health.
- **Social Impact**: Supports local entrepreneurship, preserving traditional knowledge.

By highlighting the economic, nutritional, and social impacts of commercializing underutilized fruits, this paper emphasizes the multifaceted benefits of promoting these crops. This approach not only addresses food security and

nutrition but also supports sustainable development and cultural preservation, making it a compelling subject for high-rated journals.

V. NOBILITY AND FUTURE ASPECTS

The exploration and commercialization of underutilized fruits in Northeast India embody a noble endeavor with profound implications for sustainable development. This section highlights the noble aspects of this work and outlines future research directions, supported by relevant references.

a. Nobility of the Endeavor

The pursuit of commercializing underutilized fruits in Northeast India is noble for several reasons. Firstly, it addresses the pressing issue of food security by utilizing indigenous fruit varieties that are often neglected despite their rich nutritional profiles. This can play a vital role in combating malnutrition and improving public health in rural and tribal areas where dietary diversity is limited (Kumar & Bharadwaj, 2005).

Secondly, this endeavor respects and preserves traditional knowledge and cultural heritage. The indigenous communities in Northeast India have a deep understanding of their local biodiversity, which has been passed down through generations. By promoting the use of these underutilized fruits, this project helps safeguard this invaluable knowledge and ensures its transmission to future generations (Uprety et al., 2012).

Thirdly, the project promotes environmental sustainability. Underutilized fruits are often well-adapted to local climatic conditions and require fewer inputs, such as water and fertilizers, compared to commercial crops. This makes them ideal for sustainable agriculture practices that minimize environmental impact and support biodiversity conservation (Sharma et al., 2013).

b. Future Aspects

The commercialization of underutilized fruits in Northeast India holds significant potential for future research and development. Some key areas for future exploration include:

i. Nutritional Profiling and Health Benefits:

- Comprehensive nutritional profiling of underutilized fruits to identify their bioactive compounds and health benefits. This could include studies on their antioxidant, anti-inflammatory, and anti-cancer properties (Kumar & Bharadwaj, 2005).
- Development of functional foods and nutraceuticals from these fruits to address specific health issues such as diabetes, cardiovascular diseases, and gastrointestinal disorders (Mahapatra et al., 2012).

ii. Value-Addition and Product Development:

- Research on innovative processing techniques to develop a wide range of value-added products from these fruits. This could include the use of modern technologies like freeze-drying, encapsulation, and fermentation to enhance the shelf life and nutritional quality of the products (Koley & Kaur, 2019).
- Market research to identify consumer preferences and potential markets for these products, both domestically and internationally (Roy & Rao, 2006).

iii.Sustainable Agriculture Practices:

- Investigation into the cultivation practices of underutilized fruits to improve their yield and quality. This could include studies on organic farming, intercropping, and agroforestry systems that integrate these fruits with other crops (Bhatt & Tomar, 2002).
- Development of sustainable supply chains that minimize post-harvest losses and ensure fair trade practices. This could involve training and capacity-building programs for local farmers and entrepreneurs (Sharma et al., 2013).

iv.Socio-Economic Impact Assessment:

- Longitudinal studies to assess the socio-economic impacts of commercializing underutilized fruits on local communities. This could include evaluating changes in income levels, employment opportunities, and social empowerment (Mishra et al., 2015).
- Policy research to identify the regulatory frameworks and incentives needed to support the commercialization of these fruits. This could involve collaboration with government agencies, non-governmental organizations, and international bodies (Uprety et al., 2012).

VI. CONCLUSION

Since underutilized fruit crops are reservoirs of minerals, vitamins, carbohydrates, proteins, antioxidants, they can be easily processed and converted to value added products in order to increase the livelihood of the farmers, help to reduce hunger, gives nutritional security and also provide food during off season. However, with rapid land transformation, growing connectivity, deforestation due to

uncontrolled Jhum, wood felling, etc. regrettably, resulted in the decline and loss of these species, henceforth facing rarity. The standardization of a scientific crop production, characterization of species, preservation technique, storage conditions, packaging and marketing channel needs to be encouraged and should be the prime strategies which need to be approached to farmers at the earliest. It is high time that the communities, researchers and the entrepreneurs all work together to make these minor fruit crops a commercially viable fruit crop of future. The co-existence of these wild fruit plants along with the commercial exotic crops will definitely help in achieving food security and eco-sustainability in the future.

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International Journal of Environment, Agriculture and Biotechnology
Vol-10, Issue-3; May-Jun, 2025
Peer-Reviewed International Journal
Journal Home Page Available: https://ijeab.com/
Journal DOI: 10.22161/ijeab

Effect of Different Auxin Concentrations on Rooting of Bougainvillea

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Received: 15 Apr 2025; Received in revised form: 14 May 2025; Accepted: 17 May 2025; Available online: 24 May 2025

Abstract— *The present study was conducted to evaluate the effect of different concentrations of Indole- 3 Butyric Acid (IBA) on the rooting and sprouting performance of Bougainvillea cuttings. The cuttings were treated with different IBA concentrations. The treatments were T_1 (Distilled water), T_2 (IBA 500 ppm), T_3 (IBA 1000 ppm), T_4 (IBA 1500 ppm), T_5 (IBA 2000 ppm), T_6 (IBA 2500 ppm), T_7 (IBA 3000 ppm), T_8 (IBA 3500 ppm) and T_9 (IBA 4000 ppm). Key parameters observed were days to sprouting, number of shoots per cutting, sprouting percentage, root length and number of roots per cutting. The results revealed that IBA significantly enhanced rooting and sprouting compared to untreated controls. Among all treatments T_6 (IBA 2500ppm) and T_5 (IBA 2000ppm) were found to be the most effective, resulting in earlier rooting, increased shoot formation, higher sprouting percentage, longer roots, and more roots per cutting. Higher concentrations above 3000 ppm showed reduced effectiveness, likely due to auxin toxicity. This study concludes that moderate IBA concentrations (2000–2500 ppm) are optimal for the successful propagation of bougainvillea through cuttings.*

Keywords— ***Bougainvillea, IBA, Rooting hormone, Vegetative Propagation, Root length.***

I. INTRODUCTION

Bougainvillea is a fast-growing, evergreen plant that grows like a vine in warm tropical and subtropical areas. It originally comes from parts of South America, from western Brazil to southern Argentina. It belongs to the Nyctaginaceae family and has about ten different species. The most commonly used ones in gardening are *B. spectabilis, B. glabra, and B. peruviana*. *B. peruviana* is a woody shrub can grow up to 12 meters tall, climbing or trailing with the help of stiff, thorny stems. Its leaves are simple and vary in shape, while its vibrant, petal-like bracts are a key ornamental feature, making it ideal for landscaping **Parmar (2010)**. Though, it produces seeds, bougainvillea is mainly propagated through vegetative methods such as cuttings, budding, layering, and inarching due to low seed viability **Ahmad *et al.* (2002)**. Like many perennials, it is commonly multiplied using parts like stems and roots in a warm and humid climatic condition. Plant grows and develops with the help of special chemicals called hormones. One important group of these hormones is auxins, which help with root growth, cell stretching, and overall plant development. The natural auxin called Indole-3-acetic acid (IAA) is common in plants, while synthetic versions like IBA and NAA are often used to improve plant growth, especially when growing new plants from cuttings. In North Central India a perennial shrub are generally propagated during monsoon in open condition or throughout the year under protected condition but this experiment was conducted to propagate the bougainvillea in open climate during spring season which is quite drier period as compared to monsoon using IBA. This research is particularly beneficial for commercial growers aiming to improve the efficiency and success rate of their propagation techniques in open climate during dry period.

II. MATERIAL AND METHODS

The experiment was conducted to assess effect of different auxin concentration on rooting of bougainvillea cv. Torch Glow at Horticulture Research Farm, Department of Horticulture at Kamla Nehru Institute of Physical and Social Sciences, Faridipur, Sultanpur, Uttar Pradesh, India, during February-March 2025, which is situated at about 8 km distance from district head quarter of Sultanpur in the North-East direction. The geographical situation of the farm lies at 26.30' North latitudes, 82.11' East longitude and at an altitude of 128.93' meters above the mean sea level. The hardwood cuttings of 15 cm length and pencil thickness was prepared in the month of February, and planted quick dip for 10 seconds in treatment with different concentrations of IBA (Indole- 3 butyric acid) was applied. The stock solution of 4000 ppm IBA was prepared by dissolving IBA 2g in 500ml distilled water and further concentrations was prepared by dilution of stock solution accordingly. IBA directly does not dissolve in distilled water so ethanol was used. The experiment was carried out by planting cuttings in plastic trays and filled with potting mixture which was prepared by well mixing one part of cocopeat, one part of sand and one part of vermicompost. The experiment was laid out in Completely Randomized Design with nine treatments which was replicated five times viz., T_1 (Distilled water), T_2 (IBA 500 ppm), T_3 (IBA 1000 ppm), T_4 (IBA 1500 ppm), T_5 (IBA 2000 ppm), T_6 (IBA 2500 ppm), T_7 (IBA 3000 ppm), T_8 (IBA 3500 ppm) and T_9 (IBA 4000 ppm).

III. RESULTS AND DISCUSSION

The study was conducted to evaluate how different levels of auxin (ranging from 500 ppm to 4000 ppm) influence the rooting ability of bougainvillea cuttings. The data recorded on days to sprouting, number of shoots per cutting, sprouting percentage, root length and number of roots per cutting are displayed in Table 1. The findings varied depending on the amount of auxin used. The minimum days to sprouting 08.20 days was observed in T_6 (IBA 2500ppm) which is at par with 08.40 days in T_5 (IBA 2000ppm). The maximum days to sprouting 14.20 days was noted in T_1 (Distilled water). The highest number of shoots per cutting 07.00 was observed in T_6 (IBA 2500ppm) followed by 05.60 in T_5 (IBA 2000ppm) whereas the minimum number of shoot per cutting 03.00 was found in T_1 (Distilled water). The data pertaining to sprouting percentage was affected by different auxin concentrations on rooting of bougainvillea. Results revealed that T_6 (IBA 2500ppm) exhibit maximum sprouting percentage 90.00% which is at par with 85.00% in T_5 (IBA 2000ppm). The minimum sprouting percentage 50.00% was found in T_1 (Distilled water). The maximum root length 10.50 cm was noted in T_6 (IBA 2500 ppm) followed by 07.36 cm in T_5 (IBA 2000 ppm). The minimum root length 02.66 cm was observed in T_1 (Distilled water). Similarly, maximum number of roots per cutting 36.00 was recorded in T_6 (IBA 2500ppm) which is at par with 22.50 in T_5 (IBA 2000ppm). The minimum number of roots per cutting 10.50 was found in T_1 (Distilled water). Hardwood cuttings of *Bougainvillea* cv. Mary Palmer achieved 75% rooting when treated with 1500 ppm IBA, compared to only 15% in the control, as reported by **Kale and Bhujbal (1972) and Ramdayal *et al.* (2001). Gandotra *et al.*(1975)** observed that some success has been achieved in rooting of stem cuttings in Bougainvillea with the use of synthetic auxins, especially indole- 3- butyric acid. **Panwar *et al.*(1994)** observed the best rooting in hard wood cuttings of Bougainvillea treated with IBA 2000 ppm. Overall, the findings confirm that auxin significantly affects the rooting and growth of Bougainvillea cuttings. However, its impact is highly dependent on the concentration used. Auxin levels of 2000 ppm and 2500 ppm were most effective, promoting faster sprouting, more shoots, and stronger root development, making them ideal for successful propagation of Bougainvillea. **Kanamadi *et al.* (1997)** reported that the treatment with GA at 100ppm + IBA at 2500ppm + NAA at 2500 ppm resulted in the maximum number of leaves and length of the longest shoot per cutting in Bougainvillea.

Table-1 Effect of different auxin concentrations on rooting of bougainvillea

Treatments	Treatment details	Days to Sprouting	Number of Shoots Per Cutting	Sprouting Percentage	Root Length (cm)	Number of Roots Per Cutting
T_1	**No Treatment**	14.20	03.00	50.00	02.66	10.50
T_2	**IBA 500 ppm**	12.60	03.40	65.00	02.80	14.75
T_3	**IBA 1000 ppm**	11.00	03.80	65.00	02.76	16.75
T_4	**IBA 1500 ppm**	10.20	04.40	70.00	04.38	21.75
T_5	**IBA 2000 ppm**	08.40	05.60	85.00	07.36	22.50

T_6	**IBA 2500 ppm**	08.20	07.00	90.00	10.50	36.00
T_7	**IBA 3000 ppm**	10.60	05.00	65.00	06.44	19.75
T_8	**IBA 3500 ppm**	11.00	04.40	55.00	05.34	17.00
T_9	**IBA 4000 ppm**	13.00	03.00	60.00	04.48	19.75
C.D		00.88	NS	NS	00.43	01.58
SE (m)		00.30	00.89	15.23	00.15	00.54
SE(d)		00.40	01.27	21.53	00.21	00.76
C.V		06.18	45.70	50.66	06.51	05.47

IV. CONCLUSION

The study clearly demonstrated that the application of IBA significantly influences the rooting and sprouting performance of bougainvillea cuttings. Out of all the concentrations tested, IBA at 2000 ppm and 2500 ppm showed the best results. These concentrations resulted in the shortest time to rooting and sprouting, higher sprouting percentages, greater number of shoots and roots per cutting, longer root lengths.

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International Journal of Environment, Agriculture and Biotechnology
Vol-10, Issue-3; May-Jun, 2025
Peer-Reviewed International Journal
Journal Home Page Available: https://ijeab.com/
Journal DOI: 10.22161/ijeab

Evaluation of the different varieties of Lotus *(Nelumbo nucifera)* in Prayagraj agroclimatic condition, Uttar Pradesh

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Received: 23 Apr 2025; Received in revised form: 20 May 2025; Accepted: 25 May 2025; Available online: 02 Jun 2025

Abstract— *The experiment was conducted in the Department of Horticulture, Sam Higginbottom University of Agriculture Technology and Science, Prayagraj, during 2024-2025. The experiment was laid out in Randomized Block Design (RBD) with 12 Lotus varieties and each variety was replicated 4 times. The different varieties used in the experiment were 108, Akhila, Fong Hu, Sai Thung Sui, Super lotus 14, Allahabad local lotus-1, Allahabad local lotus-2, Yellow penoy, Super lotus, Bucha, Rani red, White lotus. The result obtained showed that the variety V11: Rani red showed significantly better performance in parameters like plant height (34.01 cm), number of leaves (40.32), leaf length (23.18 cm), leaf width (20.79 cm), number of days for emergence of flower bud (21.62), flower diameter (16.92 cm), flower length (24.99 cm), duration of flowering (9.89), vase life (6.71), total number of flowers/plant (35.90), and which was found to be at par with variety V3: Fong Hu in plant height (33.00 cm), number of leaves (38.93), leaf length (22.78 cm), leaf width (24.03 cm), number of days for emergence of flower bud (22.84), flower diameter (16.25 cm), flower length (24.62 cm), duration of flowering (9.53), vase life (6.43), total number of flowers/plant (35.46), Hence, variety V11 and V3 is excellent in terms of performance and plant growth under Prayagraj agroclimatic conditions.*

Keywords— ***Lotus, varieties, plant growth, vase life.***

I. INTRODUCTION

Lotus (*Nelumbo nucifera* Gaertn.) is a signature of Indian social legacy, profoundly connected with Hindu folklore, workmanship and culture consequently lotus has been concurred the situation with the National flower of India. It is quite possibly the most appealing aquatic plant species in India existing from Kashmir to Kanyakumari displaying tremendous thermo-plasticity and phenotypic biodiversity with countless racial variations for shapes, sizes and shade of the flower going from white, pink to dark pink and having 16-160 petals [3]. The plants being profoundly aesthetic are taken advantage for beautifying ponds and lakes, it is quite possibly the most appealing native aquatic plant species. In India it is holy to Hinduism and Buddhism [12]. Lotus is a large perennial erect aquatic herb with big round floating leaves of size 20-80 cm. The flowers are generally pink or white with numerous sepals and petals and have a sacred importance. Young leaves, petioles and flowers are used as food or medicine. The species is of religious significance in South East Asia, its seeds and leaves are also eaten in this region. Each part of lotus is commercial useful: flowers on auspicious occasions, the rhizome and tender leaves are used as vegetables, seed as medicine, thalamus as fruit, leaves as plates, stalks as pickle and petals for colour extraction [9]. Wetlands are the place where water is found in abundance governs the kinds and life of organisms. Such habitats are known as sarovar, jheel, lake or pond. Marsh and swamp are the foundation of human civilisation which has been an integral part of our socio –cultural ethos in India. Historically wetlands were modified and managed by

local communities for using their resources in various ways [6]. Lotus is an important and monetary aquatic plant, which is broadly utilized as food, flower, medicine and packaging material in Chhattisgarh. Sacred lotus (*Nelumbo nucifera* Gaertn.) has been screened experimentally for different pharmacological components like anti-ischemic action, cell reinforcement movement, hepatoprotective action, mitigating action, anti-fertility activity, against arrhythmic action, anti-fibrosis activity, antiviral action, anti-proliferative action, anti-diarrhoeal action, psychopharmacological action, diuretic action, cancer prevention agent action, antipyretic action, immunomodulatory action, hypoglycaemic action, aldose reductase inhibitory action, antibacterial, aphrodisiac activity, antiplatelet action, cardiovascular action, anti-obesity activity, lipolytic action, hypocholesterolaeic action [8]. Lotus is primarily developed in India, China, Japan, Korea, South East Asia, Russia and a few nations in Africa. There are three biodiversity of Lotus utilized in China -for organic product or seeds (Lian-zi, Lian-mi), for flower (Lian hua, ha) and for rhizomes (Lian-ngau, Ou-lian). In china, lotus varieties found especially for rhizome, having diverse bloom tone, starch content. Japan delivered 822'00 tons lotus rhizomes in 1982 from an area of 6,350 ha. which has been diminished to 719'00 tons from 4,900 ha in 1998. During 1995, interestingly Japan imported lotus rhizomes, including new and processed products from China [1-2]. Taiwan produces lotus rhizome from June to November with August being top gathering time around 550 tons in 1993 [15]. South Korea delivered 9,261 tons of lotus rhizomes on 291.0 ha [1]. Mean yield of lotus rhizomes was 31.83 tons per ha. Lotus is the fourth biggest crop in South Korea area, where lotus rhizomes produce from August to December [7]. In India lotus flowers was in high demands on the occasion of Deepawali for rangoli decoration in offices, house, and shops. It flowers profusely, both the flowers and flower buds are in great demand for religious offering in temples. Sacred lotus in Chhattisgarh has genetic variability reflected in flower colour which ranges from white, pink, dark pink and having variation in number of petals which depict the single type and double type flowers, the characteristics of rhizomes and leaves and in their yield (1500 to 5000 kg/ha.). Apart from these, sacred Lotus field also support a fairly rich biodiversity of aquatic fauna, flora, insects, molluscs, other invertebrates, amphibians and birds. Unlike paddy fields which are known to be a source of methane emission, the sacred lotus plants are known to transport large volume of air from the atmosphere to the soil through big air spaces in their petiole and rhizomes, thereby aerating the soil. Sacred lotus supports wetland which helps to mitigate climate change without compromising on the provision of food and supports biodiversity [11]. Presently sacred lotus was constantly being ignored by habitat, by increasing human activities in natural wetlands for fish cultivation or for recreation purposes leading to genetic erosion of the wild lotus. The genetic diversity of lotus and its geographical pattern remains unknown. We are now facing the problem of shrinkage of natural wetlands as well ponds and reservoirs, which leads to extinction of wild lotus. The purpose of this investigation was to evaluate different varieties of lotus in agroclimatic conditions of Prayagraj to help further research and development of more sustainable and easier to reproduce lotus cultivars.

II. MATERIALS AND METHODS

The details of the various materials used and methods adopted in carrying out the experiment are presented below:

2.1 DATA ANALYSIS:

The data was analyzed using STAR.

2.2 EXPERIMENTAL SITE:

The present investigation entitled **"Evaluation of the different varieties of Lotus *(Nelumbo nucifera)* in Prayagraj agroclimatic condition**" was carried out during the year 2024-2025 in the Department of Horticulture, Sam Higginbottom University of Agriculture Technology & Sciences Prayagraj in the months of October 2024 to February 2025. The experiment was conducted on different cultivars of lotus. All the facilities necessary for cultivation, including labor were made in the department.

2.3 Varieties and Notations

Study on different varieties of lotus during 2024-25 at Horticulture Research Farm of Naini Agricultural Institute, SHUATS, Prayagraj, (Uttar Pradesh). The experiment was laid out in RBD, with 4 replications of 7 different varieties viz. V1: 108, V2: Akhila, V3: Fong Hu, V4: Sai Thung Sui, V5: Super Lotus 14, V6: Allahabad Local Lotus-1, V7: Allahabad Local Lotus-2, V8: Yellow Penoy, V9: Super Lotus, V10: Buch, V11: Rani Red, V12: White Lotus. The transplanting was done on 28/10/2024 in field condition.

2.4 Climate

The Prayagraj District comes under subtropical belt in the southeast of U.P. which experience extremely hot summer and fairly cold winter. During the winter months (Dec.-Jan) temperature falls 2-5^{0}C or even low, while in summer months (May-June) it reaches as high as 49^{0}C. Hot blowing winds are regular feature during the summers and an occasional spell of frost may be during winters. Most of the rainfall is received in the middle of July to end of September after which the intensity of rainfall decreases. The mean

annual rainfall is about 850-1100mm. However, occasional precipitation is also not uncommon during winter months.

2.5 Running status

Growth parameter

1. Plant height (cm)
2. Number of Leaves
3. Leaf Length (cm)
4. Leaf width (cm)

Floral parameter

5. Number of flowers per plant
6. Number of days for emergence of flower buds
7. Flower diameter (cm)
8. Flower length (cm)

Quality parameter

9. Vase life (days)

III. RESULT AND DISCUSSION

The experiment entitled "EVALUATION OF THE VARIETIES OF LOTUS *(Nelumbo nucifera)* IN PRAYAGRAJ AGROCLIMATIC CONDITION, UTTAR-PRADESH" was carried in the polyhouse, Department of Horticulture, Naini Agricultural Institute, Sam Higginbottom University of Agricultural, Technology and Sciences, Prayagraj. The tabulated data were statistically analyzed with a view to find out. The data present in the tabular forms shows the relevant standard error of mean deviation S (±) and the critical difference (C.D) at 5% level of significance, wherever necessary. The results emanating from the present studies are presented under appropriate heading:

Table 1: Plant height (cm) of different varieties of lotus (Nelumbo nucifera) at monthly time interval.

VARIETIES	30DAP	60DAP	90DAP	120DAP
V_1	14.91	25.54	26.12	27.00
V_2	17.04	27.21	27.86	30.24
V_3	17.98	28.48	29.36	33.00
V_4	12.17	19.63	20.90	22.84
V_5	13.72	22.89	24.53	25.28
V_6	17.26	27.22	27.91	32.16
V_7	12.46	21.79	22.06	23.84
V_8	14.36	24.16	25.88	26.82
V_9	17.40	27.72	29.13	32.24
V_{10}	12.72	22.61	23.34	24.82
V_{11}	18.29	29.13	30.62	34.01
V_{12}	15.72	25.91	26.27	29.05
F-Test	S	S	S	S
SE(d) ±	1.27	1.969	1.668	3.205
CD	2.828	4.023	3.409	6.549
CV	8.182	11.049	9.014	15.933

Significantly, higher plant height was observed in the lotus cultivar V11: Rani red (34.01 cm), which was found to be at par with cultivar V3: Fong Hu (33.00 cm), while lesser plant height was observed in the cultivar V4: Sai Thung Sui (22.84 cm).

Variation in plant height could be influenced by the parental genotypes, their genetic makeup as well as prevailing temperature during the growing period. Similar results are recorded in lotus by **H. Birkumar (2004), Pinto *et al.* (2009), Mekbib *et al.* (2020) and Srijika (2024).**

Table 4.2: Varietal observation on number of leaves of different varieties of lotus.

VARIETIES	30DAP	60DAP	90DAP	120DAP
V_1	15.82	18.03	28.05	35.16
V_2	16.54	20.20	34.06	37.02
V_3	17.67	22.80	36.46	38.93
V_4	11.81	15.45	20.10	27.64
V_5	14.96	16.91	22.92	29.40
V_6	16.95	21.51	35.91	37.28
V_7	13.28	15.85	20.47	28.65
V_8	15.30	17.12	26.65	31.19
V_9	17.21	22.35	36.19	37.63
V_{10}	14.60	16.71	21.02	29.10
V_{11}	17.98	24.55	37.05	40.32
V_{12}	16.17	19.07	30.45	35.34
F-Test	S	S	S	S
SE(d) ±	1.353	2.172	4.526	4.347
CD	2.764	4.439	9.249	8.883
CV	12.386	15.986	21.984	18.093

Significantly, higher number of leaves was observed in the lotus cultivar V11: Rani red (40.32), which was found to be at par with cultivar V3: Fong Hu (38.93), while lesser number of leaves was observed in the cultivar V4: Sai Thung Sui (27.64).

Variation in number of leaves could be influenced by the parental genotypes, their genetic makeup as well as prevailing temperature during the growing period. Similar results are recorded in lotus by **Pinto *et al.* (2009), Guo et al. (2010), Mekbib *et al.* (2020) and Srijika (2024).**

Table 4.3: Varietal observation on leaf length (cm) of different varieties of lotus.

VARIETIES	30DAP	60DAP	90DAP	120DAP
V_1	8.03	11.53	13.96	19.70
V_2	8.17	12.28	14.31	20.74
V_3	8.93	13.15	14.98	22.78
V_4	7.06	9.92	11.61	17.63
V_5	7.86	11.11	13.05	18.69
V_6	8.24	12.84	14.43	20.93
V_7	7.31	10.45	12.06	17.72
V_8	7.92	11.52	13.55	19.08
V_9	8.58	12.99	14.80	22.02
V_{10}	7.67	10.64	12.49	17.94
V_{11}	9.03	13.90	15.03	23.18
V_{12}	8.06	11.94	14.04	19.97
F-Test	S	S	S	S
SE(d) ±	0.55	1.09	0.956	1.651
CD	1.124	2.227	1.953	3.374
CV	9.634	12.996	9.866	11.653

Significantly, higher leaf length was observed in the lotus cultivar V11: Rani red (23.18 cm), which was found to be at par with cultivar V3: Fong Hu (22.78 cm), while lesser leaf length was observed in the cultivar V4: Sai Thung Sui (17.63 cm).

Variation in leaf length could be influenced by the parental genotypes, their genetic makeup as well as prevailing temperature during the growing period. Similar results are recorded in lotus by **Pinto *et al.* (2009), Guo et al. (2010), Mekbib *et al.* (2020) and Srijika (2024).**

Table 4.4: Varietal observation on leaf width (cm) of different varieties of lotus.

VARIETIES	30DAP	60DAP	90DAP	120DAP
V_1	9.44	13.48	15.43	22.52
V_2	9.51	14.48	15.86	23.20
V_3	10.44	15.02	16.91	24.03
V_4	8.59	11.56	13.22	20.94
V_5	9.00	13.05	14.97	21.87
V_6	9.77	14.75	16.06	23.28
V_7	8.73	12.20	14.35	21.52
V_8	9.24	13.34	15.21	22.18
V_9	10.08	14.89	16.35	23.83
V_{10}	8.99	12.88	14.72	21.77
V_{11}	10.63	15.44	17.39	24.79
V_{12}	9.45	14.04	15.63	22.94
F-Test	S	S	S	S
SE(d) ±	0.542	1.015	1.055	0.895
CD	1.107	2.075	2.156	1.830
CV	8.067	10.433	9.618	5.567

Significantly, higher leaf width was observed in the lotus cultivar V11: Rani red (24.79 cm), which was found to be at par with cultivar V3: Fong Hu (24.03 cm), while lesser leaf width was observed in the cultivar V4: Sai Thung Sui (20.94 cm).

Variation in leaf width could be influenced by the parental genotypes, their genetic makeup as well as prevailing temperature during the growing period. Similar results are recorded in lotus by **Pinto *et al.* (2009), Guo et al. (2010), Mekbib *et al.* (2020) and Srijika (2024).**

Table 4.5: Varietal observation on number of flowers per plant, number of days for emergence of flower bud, flower diameter, flower length and vase life of different varieties of lotus.

Variety No.	Number of flowers per plant	Number of days for emergence of flower bud	Flower diameter	Flower length	Vase life of flowers
V_1	29.81	27.12	14.67	20.32	4.86
V_2	33.36	25.59	15.62	22.98	5.33
V_3	35.46	22.84	16.25	24.62	6.43
V_4	21.86	29.14	12.86	18.94	4.04
V_5	27.53	27.9	13.99	19.58	4.26
V_6	34.09	25	15.74	23	5.58
V_7	24.16	28.78	13.44	19	4.2
V_8	27.79	27.49	14.33	20.01	4.79
V_9	34.77	24.24	16.16	23.88	6.05
V_{10}	26.02	28.42	13.74	19.34	4.24
V_{11}	35.9	21.62	16.92	24.99	6.71
V_{12}	30.7	25.81	14.94	21.49	5.24
F-test	S	S	S	S	S
SE(d) ±	3.04	2.224	2.224	1.824	0.616
CD at 5%	6.212	4.564	4.564	3.728	1.371
CV	14.27	12.022	12.022	11.989	12.094

The increase in number of flowers per plant, days for emergence of flower bud, flower diameter, Flower Length, duration of flower, vase life be influenced by the parental genotypes, their genetic makeup as well as prevailing temperature during the growing period. Similar results are recorded in lotus by **Pinto *et al.* (2009)**, **Shubhashree *et al.* (2015), Ashoka *et al.* (2023) and Srijika (2024).**

IV. CONCLUSION

From the present investigation it is concluded that the variety V11 (Rani red) is found to be best in terms of Growth parameters: plant height, number of leaves, leaf length, leaf width, number of buds per plant, Floral parameter: number of days to open flower bud, total number of flowers per plant, total number of flowers per hectare.

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International Journal of Environment, Agriculture and Biotechnology
Vol-10, Issue-3; May-Jun, 2025
Peer-Reviewed International Journal
Journal Home Page Available: https://ijeab.com/
Journal DOI: 10.22161/ijeab

Impact of Hydrogel Application and Foliar Agrochemical sprays on growth and yield of Indian Mustard (*Brassica juncea* L.)

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Received: 26 Apr 2025; Received in revised form: 24 May 2025; Accepted: 29 May 2025; Available online: 07 Jun 2025

Abstract— *Indian mustard (Brassica juncea L.), a vital rabi oilseed crop in India, faces significant productivity constraints due to water stress and nutrient limitations, particularly in semi-arid regions like Rajasthan. This study was conducted during the Rabi 2024–25 season at the Agronomy Farm, Nirwan University, Jaipur, to evaluate the impact of hydrogel and foliar-applied agro-chemicals (thiourea, salicylic acid, and NPK 19:19:19) on the growth, physiological parameters, and yield of mustard. The experiment, laid out in a factorial randomized block design with 16 treatment combinations and three replications, revealed that hydrogel application at 7.5 kg/ha significantly improved plant height (194.0 cm), dry matter accumulation (257.5 g/m), branching, chlorophyll content (3.26 mg/g), and seed yield (1829 kg/ha) compared to control. Similarly, foliar spray of thiourea @ 500 ppm consistently enhanced growth and yield attributes, recording the highest CGR (8.3 g/m²/day), RGR (74.9 mg/g/day), and seed yield (1820 kg/ha), followed by salicylic acid and NPK treatments. The results underscore the efficacy of hydrogel and stress-alleviating foliar sprays in improving water-use efficiency, physiological resilience, and mustard productivity under water-limited conditions. The integration of these technologies presents a sustainable approach to address abiotic stress in oilseed production systems.*

Keywords— ***Mustard, hydrogel, thiourea, salicylic acid, NPK 19:19:19, drought stress.***

I. INTRODUCTION

Oilseed crops have gained strategic importance in India due to their critical role in food security, industrial applications, and foreign exchange earnings. In recent years, they have become increasingly relevant amid the global energy crisis, as they serve as potential sources of biofuel and edible oils. Among these, Indian mustard (*Brassica juncea* L.) has emerged as a dominant rabi oilseed crop, contributing nearly one-third of the country's total oilseed output. It is valued not only for its edible oil content (37–49%) used widely in cooking, but also for its multifunctional uses in condiments, medicines, soaps, and as livestock feed in the form of oilcake. India ranks third globally in rapeseed-mustard production, with Rajasthan being the leading state in both area (33.70 lakh ha) and production (54.80 lakh tonnes), though the state still lags behind in realizing the crop's yield potential (2200–2400 kg/ha), primarily due to water stress and nutrient limitations (Reddy & Ramu, 2018; Anonymous, 2024). In semi-arid regions, especially in sandy soils of Rajasthan, limited soil moisture and erratic rainfall hinder crop performance. To address this, advanced crop production technologies, including hydrogels-superabsorbent polymers capable of retaining up to 400 times their weight in water have shown promising results. Hydrogel enhances soil water-holding capacity, reduces evaporation losses, and improves plant water availability during dry spells, thus significantly improving yield and

water-use efficiency (Anupama & Parmar, 2012; Dabhi *et al.,* 2013). Similarly, the application of agrochemicals such as thiourea, a sulfhydryl compound, has been effective in improving photosynthesis, canopy development, and grain filling under drought stress. Thiourea helps maintain cellular redox balance, ensuring better physiological function under adverse conditions (Nathawat et al., 2007). Salicylic acid, a naturally occurring phytohormone, further aids in osmotic adjustment, reducing water loss, and enhancing resistance to biotic and abiotic stresses including drought, heat, and chilling (Nasrin *et al.,* 2014). To complement these stress-mitigation strategies, the use of new-generation water-soluble fertilizers like NPK (19:19:19) has become increasingly popular. These fertilizers, when applied as foliar sprays, quickly correct nutrient deficiencies and improve plant health, leading to better growth, reduced dependence on chemical pesticides, and ultimately higher productivity. Their low salt index also makes them suitable for use under stress conditions, where soil nutrient availability is limited. The integration of these technologies offers a holistic and sustainable solution for enhancing mustard productivity, especially in regions facing climatic and environmental challenges (Anonymous, 2024; Reddy & Ramu, 2018).

II. MATERIALS AND METHODS

The field experiment was conducted during the *rabi* season of 2024–25 at the Agronomy Farm, School of Agricultural Sciences, Nirwan University, Jaipur (26° 51′ 42″ N, 76° 6′ 57″ E, 375 m AMSL), located in a semi-arid region with sandy loam soil and limited water availability. The study was laid out in a factorial randomized block design (FRBD) with 16 treatment combinations and three replications, involving four levels of hydrogel (0, 2.5, 5.0, and 7.5 kg/ha) and four foliar spray treatments (control, thiourea @ 500 ppm, salicylic acid @ 100 ppm, and NPK 19:19:19 @ 0.5%). The Indian mustard (*Brassica juncea* L.) variety 'Giriraj' was sown on 28th October 2024 using the *kera* method at a spacing of 30 × 10 cm with a seed rate of 4 kg/ha. Hydrogel was incorporated into the soil at sowing, while foliar sprays were applied at pre-flowering and siliqua formation stages. Standard agronomic practices were uniformly followed across all plots. Observations on growth (plant height, branches), physiological traits (chlorophyll content, CGR, RGR), biomass accumulation (dry matter), and yield components (seed, stover, and biological yield) were recorded from five randomly selected plants per plot. Data were analysed statistically using ANOVA, and treatment means were compared using LSD at a 5% significance level.

III. RESULTS AND DISCUSSION

The data presented in Table 1 and 2 clearly demonstrate the significant positive effects of hydrogel application and foliar spray of agro-chemicals on the growth and yield parameters of Indian mustard.

Effect of Hydrogel

The application of hydrogel has shown promising results in enhancing crop performance under water-limited conditions. In table 1, while the plant stand per meter row length was not significantly affected by hydrogel application, a marginal increase was noted at the highest dose (7.5 kg/ha), suggesting improved germination and early seedling establishment. Similar trends have been observed by Abedi *et al.,* (2016), who reported improved seedling emergence and early vigor due to the water-retentive properties of hydrogels. Plant height was significantly influenced by hydrogel application, increasing progressively with dose. The tallest plants (194.0 cm) were recorded with 7.5 kg/ha hydrogel, significantly higher than the control (144.8 cm), attributable to improved soil moisture and reduced drought-induced stress. These findings are consistent with those of Narjary *et al.,* (2012), who highlighted the role of superabsorbent polymers in enhancing plant growth under moisture-stress conditions by maintaining favorable soil-water relations. Dry matter accumulation showed a substantial rise with hydrogel use, with the maximum accumulation (257.5 g/m row length) at the highest dose, representing a 36.6% increase over the control. This aligns with earlier findings by Islam *et al.,* (2011), who observed enhanced biomass accumulation in hydrogel-treated crops due to prolonged water availability and better nutrient absorption. Branching patterns, both primary and secondary, were positively influenced by hydrogel, with secondary branches increasing significantly from 9.9 (control) to 13.3 (7.5 kg/ha). Improved water and nutrient uptake likely promoted enhanced apical dominance and lateral branching, as previously demonstrated by Banedjschafie *et al.,* (2008), who reported increased tillering and branching in cereals under hydrogel treatments. The data demonstrated in table 2, Crop Growth Rate (CGR) and Relative Growth Rate (RGR) showed positive trends with hydrogel. The highest CGR was recorded during 40–80 DAS (8.0 g/m²/day) and 80 DAS–harvest (5.4 g/m²/day) in the 7.5 kg/ha treatment. Although RGR differences were not statistically significant, values remained stable across treatments, reflecting sustained growth—findings consistent with Farooq *et al.,* (2009), who demonstrated that hydrogels help maintain physiological stability under episodic drought. Chlorophyll content was significantly higher in hydrogel-treated plots (3.26 mg/g at 7.5 kg/ha) than in the control (2.75 mg/g), indicating

improved photosynthetic capacity. This corresponds with the observations of Kashyap and Panda (2001), who reported that hydrogel application improved leaf water potential and chlorophyll stability under moisture stress. Significant improvements in seed yield (1829 kg/ha), stover yield (3954 kg/ha), and biological yield (5783 kg/ha) were recorded at the highest hydrogel dose, confirming that improved water retention enhances water-use efficiency and yield potential. These results corroborate with the work of *et al.,* (2017), who observed yield enhancement in various crops with polymer-based soil amendments under arid conditions.

Effect of Agro-Chemicals (Foliar Sprays)

Among the foliar-applied agro-chemicals, thiourea at 500 ppm consistently outperformed other treatments across growth and yield parameters. At harvest, plants treated with thiourea recorded a height of 192.6 cm, significantly exceeding the control (148.0 cm), indicating thiourea's role in enhancing metabolic activities under abiotic stress. Similar effects have been reported by Srivastava *et al.,* (2013), who found that thiourea enhances enzymatic activity, nitrogen metabolism, and antioxidant defense, leading to improved plant stature and productivity. Dry matter accumulation (257.9 g/m) was also highest in thiourea-treated plants, followed by salicylic acid (248.5 g/m) and NPK (237.9 g/m), likely due to improved assimilate partitioning and stress tolerance mechanisms. These findings support previous studies by Arfan *et al.,* (2007) and Ashraf *et al.,* (2010), who demonstrated the efficacy of salicylic acid and thiourea in improving water-use efficiency and metabolic resilience under stress. Thiourea also led in branching metrics, with the highest number of primary (5.1) and secondary branches (13.2) per plant. Its stress-mitigating capacity through redox regulation and enhanced photosynthate mobilization has been previously reported by Rani and Srivastava (2012). CGR and RGR were highest in thiourea treatment (8.3 and 5.5 g/m²/day for CGR; 74.9 and 26.0 mg/g/day for RGR), indicating more effective biomass accumulation and resource use. Chlorophyll content was also highest under thiourea (3.18 mg/g), further supporting its role in maintaining physiological stability under water deficit (Khan *et al.,*2015). Yield attributes mirrored these physiological improvements, with thiourea yielding 1820 kg/ha, followed by salicylic acid (1769 kg/ha) and NPK (1710 kg/ha). The effectiveness of salicylic acid (100 ppm) in improving chlorophyll content (3.10 mg/g) and CGR (8.0 g/m²/day) aligns with the findings of Hayat *et al.,* (2010), emphasizing its role in osmotic adjustment, ion homeostasis, and enhanced photosynthesis. The NPK (19:19:19) @ 0.5% spray also significantly improved growth and yield, confirming that balanced foliar nutrition is critical during critical crop stages (Fageria *et al.,* 2009).

Table 1: Effect of hydrogel and foliar spray of agro-chemicals on growth parameters of Indian mustard

Treatment	Plant stand /m row length		Plant height (cm)			Dry matter accumulation (g /m row length)			Number of primary branches /plants			Number of secondary branches /plants		
	At 29 DAS	At harvest	At 40 DAS	At 80 DAS	At harvest	At 40 DAS	At 80 DAS	At harvest	At 40 DAS	At 80 DAS	At harvest	At 40 DAS	At 80 DAS	At harvest
Hydrogel														
Control	10.0	9.3	41.8	130.4	144.8	53.5	123.7	188.4	2.5	3.3	4.0	6.8	7.0	9.9
2.5 kg/ha	10.1	9.4	51.2	161.1	171.3	67.5	155.2	235.8	2.6	3.9	4.7	7.0	8.5	11.9
5.0 kg/ha	10.2	9.5	57.3	178.8	190.8	72.4	166.1	252.8	2.7	4.2	5.0	7.2	9.3	12.9
7.5 kg/ha	10.3	9.6	57.5	182.1	194.0	73.1	169.1	257.5	2.7	4.3	5.2	7.3	9.5	13.3
SEm±	**0.57**	**0.10**	**1.2**	**3.9**	**4.3**	**1.5**	**3.2**	**5.5**	**0.05**	**0.10**	**0.11**	**0.16**	**0.23**	**0.30**
CD at 5%	**NS**	**0.29**	**3.4**	**11.2**	**12.3**	**4.2**	**9.3**	**15.8**	**NS**	**0.28**	**0.32**	**NS**	**0.66**	**0.86**
Agro-chemicals (Foliar spray)														
Water spray	10.0	9.3	50.6	138.0	148.0	64.2	125.9	190.3	2.6	3.4	4.0	6.8	7.2	10.1

Thiourea @500 ppm	10.3	9.5	53.1	178.7	192.6	68.3	167.9	257.9	2.7	4.3	5.1	7.3	9.5	13.2
Salicylic acid @100 ppm	10.1	9.4	51.5	163.9	175.7	67.5	163.5	248.5	2.6	4.1	4.9	7.2	9.0	12.7
NPK (19:19:19) @0.5 %	10.2	9.5	52.6	171.7	184.5	66.6	156.8	237.9	2.6	3.9	4.7	7.0	8.6	12.0
SEm±	**0.3**	**0.2**	**1.2**	**3.9**	**4.3**	**1.5**	**3.2**	**5.5**	**0.05**	**0.10**	**0.11**	**0.16**	**0.23**	**0.30**
CD at 5%	**NS**	**NS**	**NS**	**11.2**	**12.3**	**NS**	**9.3**	**15.8**	**NS**	**0.28**	**0.32**	**NS**	**0.66**	**0.86**

Table 2: Effect of hydrogel and foliar spray of agro-chemicals on CGR, RGR, Chlorophyll content and Yield (kg/ha) of Indian mustard

Treatment	**Crop growth rate (g /m^2 /day)**		**Relative growth rate (mg /g /day)**		**Chlorophyll content (mg /g)**	**Yield (kg/ha)**		
	At 40 - 80 DAS	**At 80 DAS - at harvest**	**At 40 - 80 DAS**	**At 80 DAS - at harvest**	**At 55 DAS**	**Seed yield**	**Stover yield**	**Biological yield**
Hydrogel								
Control	5.8	3.9	69.1	25.5	2.75	1400	2857	4257
2.5 kg/ha	7.3	4.9	68.9	25.3	3.06	1674	3542	5215
5.0 kg/ha	7.8	5.3	68.8	25.4	3.22	1797	3863	5660
7.5 kg/ha	8.0	5.4	69.4	25.4	3.26	1829	3954	5783
SEm±	**0.2**	**0.2**	**1.4**	**0.7**	**0.04**	**40**	**90**	**100**
CD at 5%	**0.6**	**0.5**	**NS**	**NS**	**0.11**	**115**	**259**	**290**
Agro-chemicals (Foliar spray)								
Water spray	5.1	3.9	70.9	25.0	2.77	1399	2924	4323
Thiourea @500 ppm	8.3	5.5	74.9	26.0	3.18	1820	3897	5717
Salicylic acid @100 ppm	8.0	5.2	73.8	25.4	3.10	1769	3795	5564
NPK (19:19:19) @0.5 %	7.5	4.9	71.4	25.1	3.23	1710	3601	5311
SEm±	**0.2**	**0.2**	**1.4**	**0.7**	**0.04**	**40**	**90**	**100**
CD at 5%	**0.6**	**0.5**	**NS**	**NS**	**0.11**	**115**	**259**	**290**

IV. CONCLUSION

The study clearly demonstrates that both hydrogel application and foliar agro-chemical treatments significantly enhance crop growth, physiological efficiency, and yield under water stress conditions. The application of hydrogel, particularly at 7.5 kg/ha, improved plant height, dry matter accumulation, branching, and chlorophyll content by maintaining better soil moisture and reducing drought-induced stress. Similarly, foliar application of thiourea at 500 ppm proved most effective among the agro-chemicals, enhancing crop growth rate, chlorophyll content, and yield components by supporting physiological and biochemical resilience under limited water availability.

ACKNOWLEDGEMENTS

The authors are grateful to the Vice Chancellor, School of Agricultural Sciences, Nirwan University, Jaipur for taking their keen interest and encouragement to carry out the research work.

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International Journal of Environment, Agriculture and Biotechnology
Vol-10, Issue-3; May-Jun, 2025
Peer-Reviewed International Journal
Journal Home Page Available: https://ijeab.com/
Journal DOI: 10.22161/ijeab

A Comparative Study of Nanoparticles: Properties and Applications in the Textile Industry

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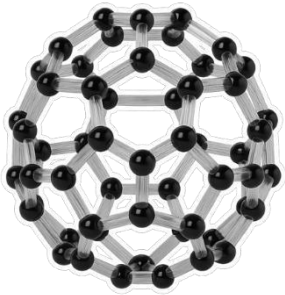
Received: 29 Apr 2025; Received in revised form: 26 May 2025; Accepted: 02 Jun 2025; Available online: 07 Jun 2025

Abstract— *This review explores the multidisciplinary realm of nanotechnology, highlighting its principles, historical evolution, and wide-ranging applications. Beginning with an overview of nanoscience and its foundational concepts, the paper delves into nanomaterials' classification and synthesis methods, including both top-down and bottom-up approaches. A comparative insight into green synthesis and conventional chemical synthesis of nanoparticles is also discussed, where green synthesis is emphasized as an eco-friendly, sustainable, and less toxic alternative, in contrast to chemical synthesis, which often involves hazardous reagents and generates harmful by-products. The paper further emphasizes the unique properties of nanomaterials that differ significantly from their bulk counterparts, making them suitable for diverse applications. Key areas of focus include the role of nanotechnology in electronics, medicine, environmental protection, and agriculture. Additionally, the paper addresses potential risks, toxicity concerns, and the prospects of nanotechnology, stressing the importance of responsible development and application. This comprehensive review aims to provide a foundational understanding of nanotechnology and its transformative potential across various sectors.*

Keywords— ***Nanotechnology, sustainability, synthesis, application***

Introduction

A nanoparticle is an ultra-fine particle, invisible to the unaided human eye, typically measuring between 1 and 100 nanometers in diameter. Owing to their minuscule scale, these particles often possess unique and remarkable physical and chemical properties that distinguish them from their larger counterparts. This classification also extends to slightly larger particulate matter, including nanoscale fibres and nanotubes measuring less than 100 nanometers in at least one dimension. (Aruna *et al.,*2023; Wiesenthal *et al.,*2011; Mishra *et al.,*2014). When a bulk material is broken down into minuscule particles with one or more dimensions, such as length, width, or thickness, within the nanometre scale, these individual nanoparticles begin to demonstrate extraordinary and often unpredictable properties that diverge significantly from those of the original bulk substance. This nanometre scale marks a pivotal threshold where the material's characteristics shift from the predictable, continuous behaviour typical of bulk matter to the intriguing, quantum-like behaviour observed at the atomic and molecular level. (Purushotham, 2012; Jeevani, 2011).



For more than thirty years, the textile industry has actively harnessed the potential of nanotechnology, integrating nanoparticles either by embedding them directly into fabric structures or by meticulously engineering their distribution within the fibres themselves. This innovative approach has revolutionised textile functionality, paving the way for advanced materials with enhanced performance and novel properties.(Yang and Westerhoff, 2014Nano-textiles provide a wide array of advanced functional advantages, including superior chemical resistance, increased mechanical durability, water repellency, extended lifespan through anti-ageing properties, antimicrobial effectiveness, self-cleaning abilities, and robust protection against ultraviolet (UV) radiation. These enhanced features position nano-textiles at the forefront of high-performance and smart fabric innovations. (Thomas *et al.,*2006; Singh *et al.,*2023) Currently, the textile industry is placing significant emphasis on investigating the application of metallic nanoparticles (MNPs) to advance fibre manufacturing processes and develop fabrics with innovative or significantly improved properties. This cutting-edge exploration aims to unlock new functionalities and elevate the performance of textile materials to unprecedented levels. (McArthur *et al.,*2012) The incorporation of nanoparticles into textile materials has been the focus of extensive research to create finished fabrics that exhibit a variety of enhanced functionalities. For instance, silver nanoparticles (nano-Ag) have been widely utilised to endow textiles with potent antibacterial properties, significantly improving their hygiene and durability.(Lee *et al.,*2003; Durán *et al.,*2007), nano-TiO_2 for UV-blocking and self-cleaning properties (Xin *et al.,*2004; Fei *et al.,*2006; Qi *et al.,*2007) and ZnO nanoparticles for antibacterial and UV-blocking properties (Wang *et al.,*2004; Baglioni *et al.,*2003; Wang *et al.,*2005; Vigneshwaran *et al.,*2006).

Metal nanoparticles (MNPs) have been widely explored for textile functionalization owing to their unique physicochemical and biological characteristics. Their remarkable properties make them ideal candidates for enhancing textile performance across various applications. (Mehravani *et al.,*2021; Ribeiro *et al.,*2020). Metal nanoparticles (MNPs) serve as pivotal contributors to this technological advancement, owing to their exceptional surface characteristics that deliver significantly greater efficacy compared to traditional bulk additives. Their high surface-area-to-volume ratio amplifies their functionality, enabling enhanced performance in textile applications. (Rivero *et al.,*2015; Ribeiro *et al.,*2018Metal nanoparticles are composed entirely of metallic elements and are renowned for their unique electrical properties, primarily attributed to the phenomenon of localised surface plasmon resonance (LSPR). Notably, copper (Cu), silver (Ag), and gold (Au) nanoparticles display a broad absorption band within the visible region of the solar electromagnetic spectrum. These nanoparticles are extensively utilised across various scientific disciplines due to their exceptional attributes, including controlled synthesis based on facets, size, and shape, which significantly enhance their functional capabilities. (Khan *et al.,*2019).

Nanotechnology plays a vital role in tackling contemporary challenges within the textile industry, particularly the growing demand for sustainable, environmentally friendly materials and manufacturing processes. By integrating nanomaterials, the industry is empowered to create cutting-edge textile solutions that align with shifting consumer preferences, ranging from intelligent fabrics for wearable technology to high-performance protective textiles and eco-conscious materials that support a greener planet. The true significance of nanotechnology lies in its transformative potential to push the frontiers of textile science, drive innovation, and elevate market competitiveness across diverse sectors. (Prasad *et al.,*2023).

Types of metallic nanomaterials used in textile

To understand the practical use of nanoparticles in textiles, it is essential to explore the specific types of metallic nanomaterials that have demonstrated effectiveness in this domain

Silver nanoparticles (AgNPs)

Silver nanoparticles are nanoscale particles of silver typically ranging in size from 1 to 100 nanometers. Although often referred to simply as "silver," many of these nanoparticles consist largely of silver oxide, owing to their exceptionally high surface-area-to-volume ratio, which increases surface reactivity. Depending on the intended application, silver nanoparticles can be synthesized in a variety of shapes. Among the most commonly utilised forms are spherical particles, octagonal structures, and ultra-thin sheets, each offering distinct properties suited to specific functional requirements (Graf *et al.,*2003).

Green synthesis of silver nanoparticles was achieved using *Azadirachta indica* (Neem) leaf extract. This eco-friendly process involved mixing silver nitrate with the extract, 1

mm $AgNO_3$ solution. 10 ml of extract was added to 90 ml of $Agno_3$. UV-Vis peak at 450 nm confirmed synthesis. leading to nanoparticle formation indicated by a colour change. Characterisation confirmed size and shape. This method is cost-effective, sustainable, and avoids harmful chemicals (Ahmed *et al.,* 2016).

Silver nanoparticles (AgNPs) were synthesised through the chemical reduction of a 12 mm aqueous solution of $AgNO_3$. The reaction was conducted under an argon atmosphere using 70 ml of the silver nitrate solution combined with polyvinylpyrrolidone (PVP), maintaining a molar ratio of 34:1 between PVP repeating units and silver ions. Additionally, 21 ml of Aloe Vera extract was added to the mixture. This solution was subjected to ultrasonic agitation for 45 minutes at room temperature, followed by a controlled heating process at a rate of 2°C per minute until reaching 80°C. The reaction was sustained for two hours, resulting in a clear solution containing finely dispersed nanoparticles, which were then isolated by simple filtration (Shenashen *et al.,*2014; Gloria *et al.,*2017).

Zinc oxide nanoparticles (ZnO)

Zinc oxide nanoparticles are ultra-fine particles of zinc oxide (ZnO) with diameters typically under 100 nanometers. Due to their nanoscale dimensions, they exhibit an exceptionally high surface area-to-volume ratio, which significantly enhances their catalytic efficiency and reactivity, making them valuable in a wide range of applications (Shamhari *et al.,*2018). The most common use of ZnO nanoparticles is in sunscreen (Smijs and Pavel, 2011). They are employed for their excellent UV light absorption capabilities, while their wide bandgap ensures full transparency to visible light, making them ideal for applications needing invisible UV shielding (Smijs and Pavel, 2011; Osmond and Mccall, 2010). They are also being explored for their antimicrobial properties in packaging and use in UV-protective materials like textiles, enhancing both safety and functionality (Singha *et al.,*2020; Mousa and Khairy, 2020).

Zinc oxide nanoparticles were green synthesised using *Syzygium aromaticum* (clove) extract and zinc nitrate, followed by calcination at 400°C. UV–Vis showed a peak at 376 nm; TEM revealed 10–30 nm spherical particles. The nanoparticles exhibited strong antibacterial activity, making this eco-friendly method effective, sustainable, and suitable for biomedical applications (Naiel *et al.,* 2022)

Copper nanoparticle (CuO)

A copper nanoparticle is a nanoscale particle composed of copper, typically ranging in size from 1 to 100 nanometers. (Din, *and* Rehan, 2017Copper nanoparticles can be chemically synthesised, with one approach involving the reduction of copper hydrazine carboxylate in an aqueous solution under reflux or ultrasonic conditions within an argon environment, resulting in the formation of copper oxide or metallic copper clusters. (Dhas *et al.,*1998; Rani, 2015).

Copper oxide nanoparticles were green synthesised using *Calotropis gigantea* leaf extract and copper sulfate solution. The mixture was stirred and heated at 80°C for 2 hours, forming CuO NPs. UV–Vis showed absorption at 285 nm; XRD confirmed crystalline nature with ~18 nm size. The nanoparticles exhibited strong antimicrobial activity, proving this eco-friendly method effective and sustainable (Alhalili, 2022).

Gold Nanoparticles (AuNPs)

Gold nanoparticles (AuNPs) are nanoscale particles composed of gold, known for their distinctive physical and chemical characteristics. They possess the ability to absorb and scatter light across the visible and near-infrared spectrum. (Rad *et al.,*2011; Compostella *et al.,*2017).

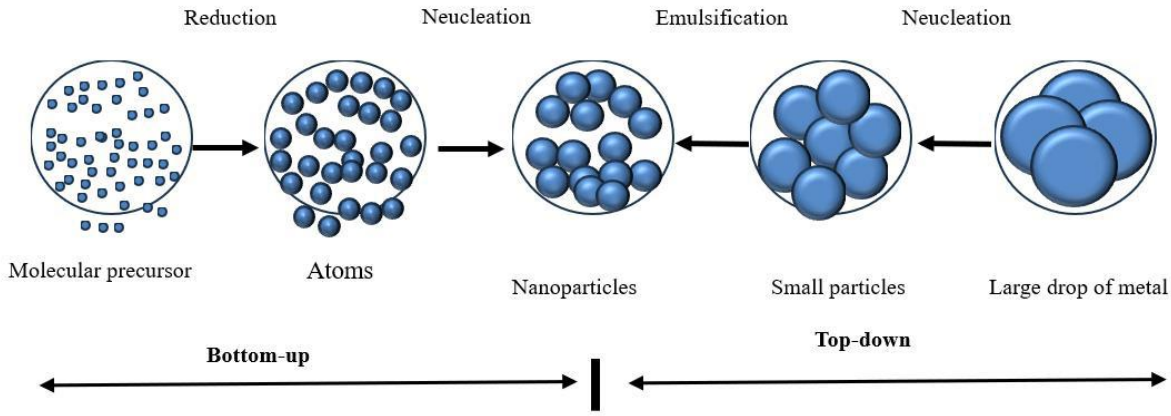
The synthesis of gold nanoparticles began in 1951, when Turkevich employed sodium citrate as a reducing agent to produce them. Since that time, various other reducing agents—such as gallic acid, hydrogen peroxide, and hydrazine—have been utilised by researchers. Subsequently, Brust Schiffrin introduced a two-phase synthesis method in 1994, further advancing the field. However, the use of agents such as citric acid, sodium borohydride ($NaBH_4$), polyethene glycol (PEG), hexadecyltrimethylammonium bromide (CTAB), trioctylphosphine (TOPO), and oleylamine (OAm) poses concerns due to their toxic, irritating, flammable, or environmentally hazardous nature. As a result, greener synthesis approaches have recently emerged, utilising eco-friendly alternatives like plant extracts, bacteria, yeasts, fungi, and enzymes in place of conventional chemical reducing agents. (Kalimuthu *et al.,*2020; Fan *et al.,*2020)

Synthesis of nanoparticles

The functionality of nanoparticles is strongly influenced by their synthesis methods. Therefore, a discussion of the synthesis approaches is imperative for a comprehensive understanding.

The nanoparticles are synthesised by various methods that are categorised into bottom-up or top-down methods.

Top-Down and Bottom-Up Approaches



1. Top-down synthesis

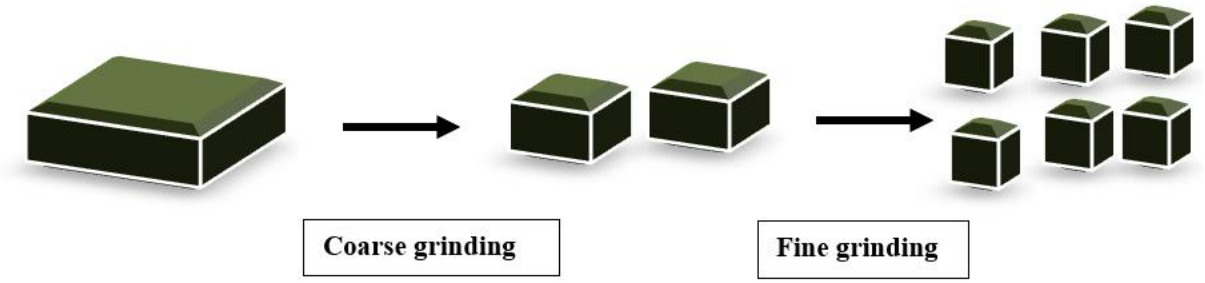
In top-down synthesis, a larger bulk material is broken down into smaller molecular units, which subsequently convert into nanoparticles. Techniques such as grinding, milling, and physical vapour deposition are commonly used in this approach, as they involve the disintegration of larger structures into nanoscale particles (Iravani, 2011)

A. Mechanical milling

Among the diverse top-down techniques, mechanical milling stands out as the most widely utilised method for producing a range of nanoparticles. This process involves the milling and subsequent annealing of nanoparticles, where various elements are ground together under an inert atmosphere to prevent unwanted reactions during synthesis (Yadav *et al.,*2012)

Mechanical milling involves the use of balls enclosed within containers and is typically performed using high-energy systems such as planetary or shaker mills. This impact-driven process delivers intense energy, facilitating the breakdown of materials into nanoscale particles (Gorrasi and Sorrentino, 2015). Ball-milled carbon nanomaterials represent a distinctive category of nanoparticles with promising potential to address critical demands in energy storage, energy conversion, and environmental remediation. Their unique structural and functional properties make them highly versatile for advanced technological applications (Yadav *et al.,*2012; Lyu *et al.,*2017).

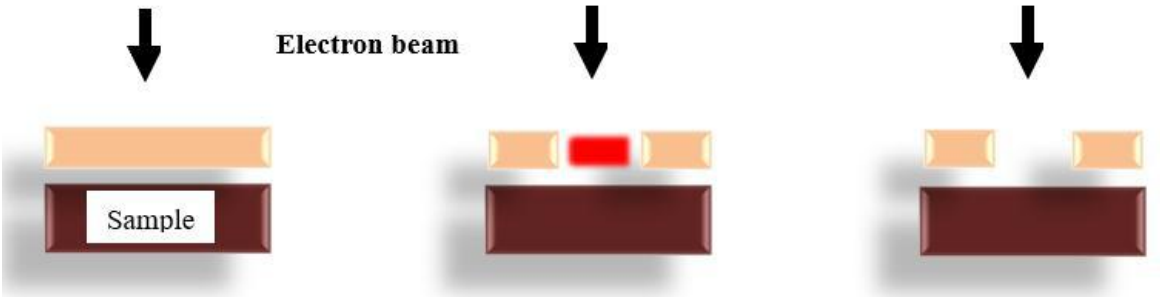
Basic material



B. Lithography

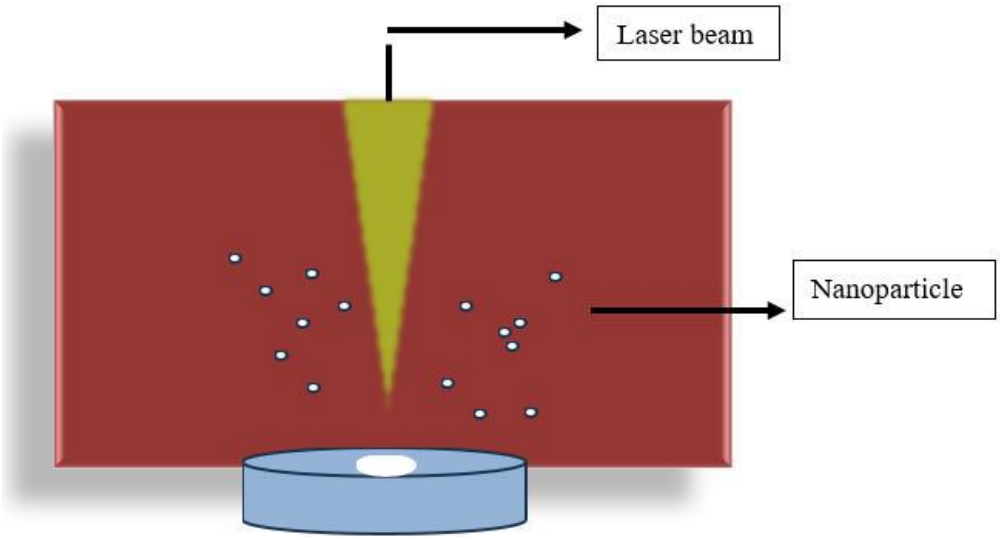
Lithography is a technique used to pattern specific shapes or structures onto a light-sensitive material by selectively removing portions to form the desired design. One of the key advantages of nanolithography is its precision in fabricating anything from a single nanoparticle to organised clusters with controlled shape and size. However, its limitations include the need for sophisticated, complex equipment and the high costs involved in the process (Hulteen *et al.,*1999)

Lithography commonly employs a focused beam of light or electrons to fabricate nanoparticles, making it a valuable and precise technique in nanoscale manufacturing (Pimpin and Srituravanich, 2012). Lithography is primarily divided into two main types: masked and maskless. In maskless lithography, nano-patterns can be directly printed without the use of a physical mask, allowing for greater design flexibility. This method is also cost-effective and relatively simple to implement (Brady *et al.,*2019).



C. Laser ablation

Laser ablation synthesis in solution is an efficient and straightforward method for producing nanoparticles using various solvents. When a laser beam irradiates metal targets submerged in a liquid medium, it generates a plasma plume that condenses to form nanoparticles (Amendola and Meneghetti, 2009)

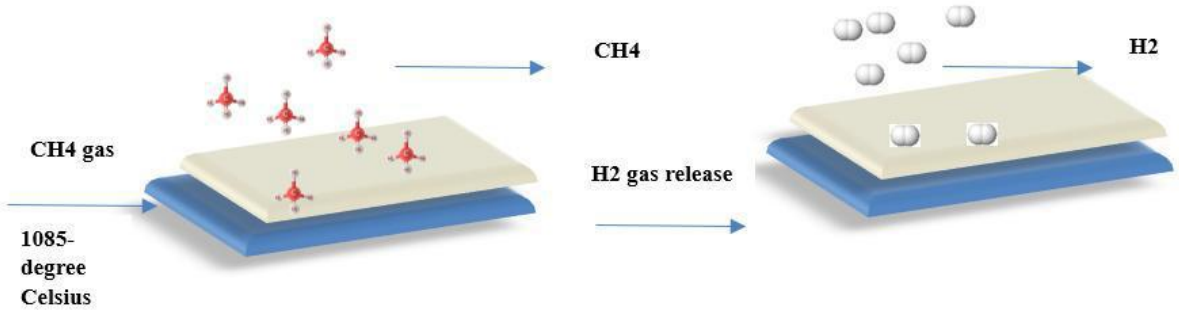


2. Bottom-up approach

The bottom-up approach is generally preferred for synthesizing nanoparticles in food-related applications, as it offers superior control over particle size and surface structure compared to other methods (Khan *et al.,*2019). The bottom-up approach enhances particle size uniformity and distribution stability by utilizing self-assembly processes of the constituent materials (Sinha *et al.,*2013)

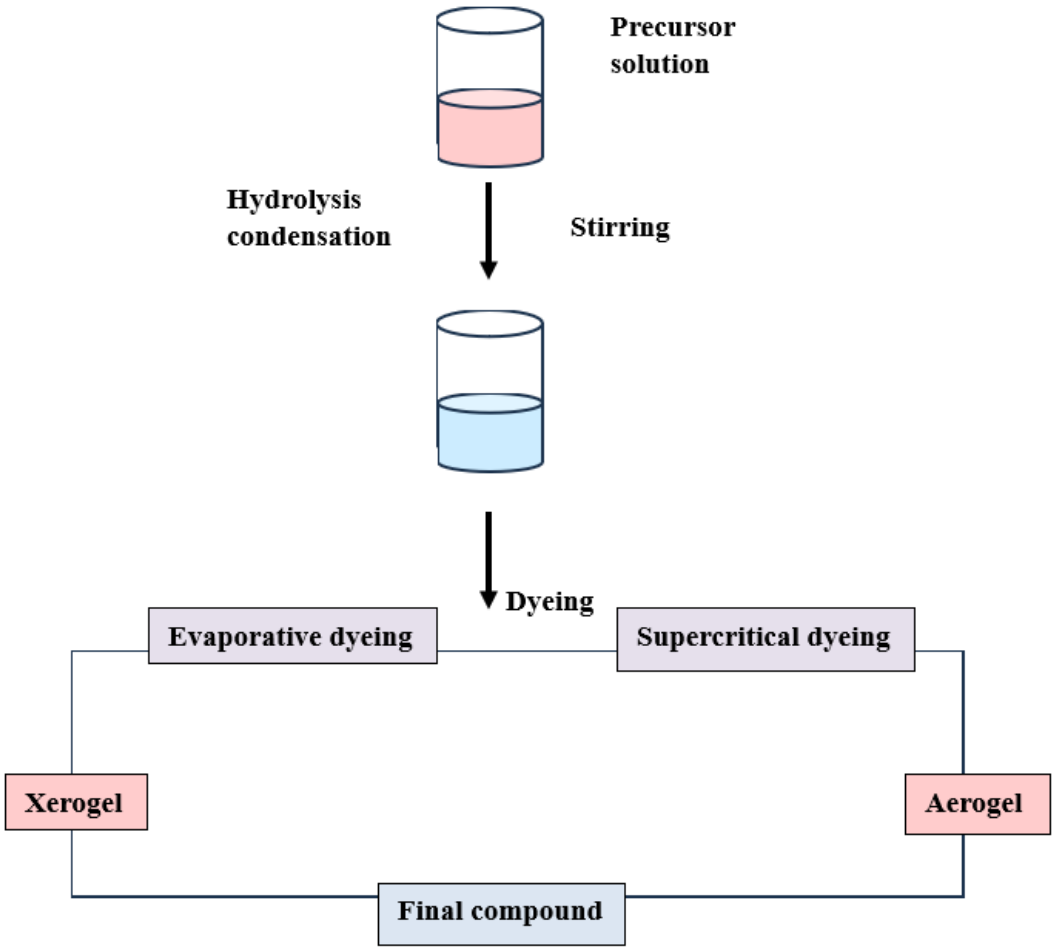
1. Chemical vapor deposition (CVD).

Chemical Vapor Deposition (CVD) forms a thin film on the surface of a substrate through a chemical reaction involving vapor-phase precursors (Dikusar *et al.,*2009). Precursors are considered suitable for Chemical Vapor Deposition (CVD) if they possess high volatility, exceptional chemical purity, stable evaporation properties, low cost, non-toxic nature, and an extended shelf life. Moreover, their decomposition should not result in any residual contaminants. Variants of CVD include vapor phase epitaxy, metal-organic CVD, atomic layer epitaxy, and plasma-enhanced CVD. One of the key advantages of this technique is its ability to produce nanoparticles that are highly pure, uniform, robust, and structurally consistent. (Ago, 2015). Chemical Vapor Deposition (CVD) is a highly effective method for producing nanomaterials of exceptional quality (Machac *et al.,*2020). It is also widely recognized for its capability to fabricate two-dimensional nanoparticles with precision and consistency (Baig *et al.,*2021).



2. Sol-gel process

The sol-gel method, a wet-chemical technique, is extensively employed for the synthesis of nanomaterials (Das and Srivasatava, 2016; Baig *et al.,*2021). In the sol-gel process, metal alkoxides or metal-based precursors in solution undergo hydrolysis, condensation, and thermal decomposition, forming a stable sol or colloidal solution. As hydrolysis and condensation progress, the gel's viscosity increases. Particle size can be precisely controlled by adjusting factors such as precursor concentration, pH, and temperature. During the maturation phase, which may take several days, the solvent is gradually removed, Ostwald ripening occurs, and phase transformations facilitate the formation of a solid structure. Unstable chemical components are separated in the process, and the resulting nanomaterial is eco-friendly, offering numerous advantages through this sustainable synthesis method (Patil *et al.,*2021). The sol-gel technique offers numerous advantages, including the ability to produce materials with uniform quality, operate at relatively low processing temperatures, and the simplicity of fabricating composites and intricate nanostructures with precision and efficiency (Parashar *et al.,*2020).



3. Biosynthesis

Biosynthesis is an eco-conscious and sustainable method for producing nanoparticles that are both non-toxic and biodegradable, making it a highly environmentally friendly alternative to conventional synthesis techniques (Bhardwaj *et al.,*2020). Eco-friendly green synthesis of nanoparticles involves using natural precursors in place of traditional chemicals for both bioreduction and capping processes. The nanoparticles produced through this biosynthetic route possess distinctive and improved properties, making them highly suitable for a range of biomedical applications (Hasan, 2015).

(Oves *et al.,*2022) Employed a bottom-up synthesis strategy and demonstrated that silver nanoparticles (AgNPs) produced using *Conocarpus lancifolius* fruit extract present a sustainable, environmentally friendly substitute for traditional chemical synthesis methods. Characterisation through UV-Vis spectroscopy, XRD, TEM, and FT-IR revealed that the AgNPs were spherical with an average particle size of 26.28 nm.

Approach	**Method**	**Nanoparticles**
Top-down synthesis	Mechanical milling	Metal, oxide and polymer-based
	Lithography	Metal based
	Laser ablation	Carbon and metal oxide-based
Bottom-up synthesis	Chemical vapor deposition (CVD).	Carbon and metal-based
	Sol-gel process	Carbon, metal and metal oxide based
	Biosynthesis	Organic polymers and metal-based

Different analytical techniques and their purposes in studying nanoparticles

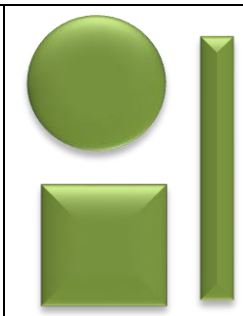
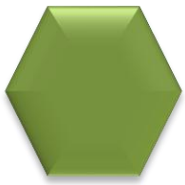
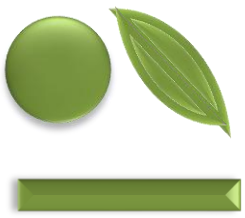
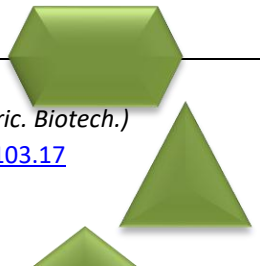
Characterization of nanoparticles is crucial for evaluating their structure, size, and other properties. The following analytical techniques provide insight into these attributes.

Name of test	**Objective**	**References**
Particle size analyser (PSA)	Utilized to assess the particle size distribution within a given sample.	(Gee *and* Bauder, 1986).
X-ray diffraction XRD	Employed for the characterisation of nanopowders of various sizes, it offers valuable insights and aids in linking microscopic observations with the properties of the bulk material.	(Holder *and* Schaak 2019).
Transmission electron microscopy (TEM)	Captures high-resolution images using a light microscope and is commonly used to examine the structure and detect the presence of nanoparticles.	(Liu, 2005).
Scanning electron microscope (SEM)	Provides a three-dimensional view based on how the electron beam interacts with the surface of the specimen.	(Goldstein *et al.,*2017).
Scanning tunnelling microscopy (STM)	Used to investigate the local electronic structure of metal nanoparticles, along with analysing their presence and overall structural characteristics.	(Kano *et al.,*2015).
Ultraviolet-visible spectroscopy (UV-Vis)	Employed for the optical analysis of materials and to confirm the successful synthesis of nanoparticles.	(Rathod *and* Waghuley, 2015).
Fourier transform infrared spectroscopy (FTIR)	Used to analyse the surface chemistry of metal nanoparticles. It helps identify organic, inorganic, and polymer-based materials by scanning samples with infrared light and is also effective in detecting functional groups within the material.	(Dutta, A. 2017).
Zeta potential instruments/zeta potential	Measures the electrical charge on the surface of particles suspended in a liquid and is used to assess the stability of metal nanoparticles in solution.	(Doane *et al.,*2012).

Field emission scanning electron microscope (FESEM)	Employed to obtain detailed images of the microstructure of materials.	(Cik *et al.,*2015).
Nanoparticle tracking analysis (NTA)	Utilised to determine the size distribution of nanoparticles in liquid suspensions, analysing numerous particles individually and simultaneously on a particle-by-particle basis.	(Gross *et al.,*2016)
Centrifugation	Used to isolate the synthesised nanoparticles from the reaction mixture.	(Kahnouji *et al.,*2019)

Characteristics of metal-based nanoparticles

A deeper understanding of the behavior and effectiveness of nanoparticles requires an analysis of their physical and chemical characteristics.

Nanoparticles and its Size	**Shape of Nps**		**Aspect ratio**	**Surface area**	**Solubility**	**Optical property**
AgNp 1–100 nm (Graf *et al.,*2003) (Sriram *et al.,*2012).	Spheres (diameter 40–80 and 120–180 nm; two different samples), platelets (20–60 nm), cubes (140–180 nm), and rods (diameter 80–120 nm, length > 1000 nm (Helmlinger *et al.,*2016)		AgNPs synthesized with 40, 80, and 120 mM Fe3+ have aspect ratios 490, 1156, and 236, respectively (Saw *et al.,*2019).	23.81 m2/g (Zhou *et al.,*2009).	Excellent water solubility and long-term colloidal stability. (Jana *et al.,* 2007; Rahmati-Abkenar and Manteghian, 2020.)	Highly reflective, can be made transparent (Stepanov *et al.,*2011).
ZnO 1−100 nm (Khan *et al.,*2019).	Hexagonal pyramid-shaped (Thirugnanasambandan *et al.,*2021)		For rod-shaped ZnO nanoparticles is approximay 6 (Wang *et al.,*2018).	64.4 m 2 g (Bai *et al.,*2011)	0.3–3.6 mg/L in aqueous medium (Siddiqi and Husen, 2016).	high optical transparency and Luminescence (Swati *and* Mahendra, 2015). $E_{g=}$3.14 eV. (Katiyar *et al.,*2018)
CuONp 1–100 nm (Khan *et al.,*2019).	spheres, rods and spindles (Thit *et al.,*2015)		For copper nanowires (CuNWs), range from 500 to 1666 (Saw *et al.,*2019)	5−10 m2 /g (Ndolomingo and Meijboom, 2016)	Minimal Cu solubility is found at pH 9–11, although above pH 11, CuO solubility increases slightly due to complexing with hydroxide ions (Hortin *et al.,*2020).	have maximum absorption in the ultraviolet range E_g = 2.74 eV. (AI *et al.,*2023)
AuNp	triangular, pentagonal,		For gold nanorods	5.8–107 m2 /g	AuNPs have great solubility in	Highly reflective

1–100 nm (Khan *et al.,*2014)	hexagonal, and spherical (Hammami *and* Alabdallah, N. M. 2021).		ranged from 1.83 to 5.04 (Feng *et al.,*2015)	(Ahmad *et al.,*2014)	organic solvents such as toluene, while the hydrophilic (1-mercaptoundec-11-yl) tetraethyleneglycol functionalized gold nanoparticles dissolve in water and alcohols (Guo *et al.,*2015).	(Stepanov *et al.,*2011).

Types of nanoparticles	**Green synthesis**	**Chemical Synthesis**
AgNp	Silver nanoparticles synthesized using $AgNO_3$, $NaBH_4$, and chitosan showed strong stability. Low molecular weight chitosan produced ~4–6 nm uniform particles. TEM, UV-vis, and zeta potential confirmed excellent dispersion, size control, and long-term colloidal stability, highlighting their potential in biomedical and environmental applications (Kulikouskaya et al., 2022)	Silver nanoparticles (9–30 nm) were synthesized and characterized using UV-Vis, TEM, EDX, and HEED. Smaller particles (9, 11 nm) showed strong antibacterial activity against MRSA, S. aureus, E. coli, and P. aeruginosa, proving size-dependent antimicrobial effectiveness at low concentrations (Guzmán et al., 2009)
ZnONp	Aloe vera-mediated ZnO nanoparticle synthesis achieved ~100% yield in 6 h with 25% extract. Particles (25–55 nm) showed strong UV absorption (358–375 nm), PL emission shift, wurtzite structure, bio-organic capping, and antimicrobial potential, confirming suitability for biomedical and optoelectronic applications (Sangeetha et al., 2011)	This study compares green and chemical synthesis of ZnO nanoparticles. Green synthesis using *Coriandrum sativum* produced purer, smaller (66 nm) particles with better crystallinity, while the chemical method yielded larger (81 nm), flower-like structures. The green method proved eco-friendly, cost-effective, and scalable (Gnanasangeetha and Sarala Thambavani, 2013)
CuNp	This study demonstrates a green, eco-friendly synthesis of stable, cubical copper nanoparticles (CuNPs) using *Azadirachta indica* leaf broth. Optimal conditions included 20% broth, 7.5×10^3 M $CuCl_2$, 85 °C, and ph 6.6, yielding 48 nm, crystalline, monodispersed CuNPs (Nagar and Devra, 2018)	Copper nanoparticles were synthesised using ascorbic acid. Optimal results appeared at 60 min (red colour, stable), ph 10 (plasmon peak at 573 nm), and PEG: Cu^{2+} ratio 18:1 (smallest, uniform particles, ~10–20 nm, minimal aggregation by TEM) (Dang et al., 2011)
AuONp	This study synthesized gold nanoparticles (GNPs) using four plant extracts. UV-vis peaks appeared at 535–538 nm (SO, LC, PeG) and 568 nm (PuG). DLS showed PuG had larger particles (30–70 nm), others had 1–8 nm. GNPs were stable, biocompatible, and gold-confirmed by EDS(Elia et al., 2014)	This study reports the chemical synthesis of gold nanoparticles from copper anode slime using sodium citrate and VenMet solution. Results showed particle size reduced from 700 nm (cubic) to 10–35 nm (spherical) at 45 °C and 1200 rpm, confirmed by SEM, DLS, TEM, EDS, and XRD (Abkenar and Naderi, 2016).

Varied applications of metallic nanoparticles

The distinctive properties of nanoparticles translate into a wide array of applications, particularly in the textile sector. The following section outlines these applications in detail.

Silver Nanoparticles (AgNPs)

Antimicrobial Properties: Prevent bacterial and fungal growth, making fabrics ideal for medical textiles, sportswear, and undergarments.

Odour Control: Reduce unpleasant odours caused by microbial activity.

(Zhang *et al.,*2009) state that nano-silver colloidal solutions, synthesised using $AgNO_3$ and HBP-NH_2 at room temperature, exhibit excellent stability and antimicrobial properties. The silver nanoparticles, averaging 18 nm, were effectively fixed onto cotton fabric, as confirmed by SEM and XPS analysis. The treated fabric demonstrated over 98.77% bacterial reduction against *S. aureus* and *E. coli* even after 20 washes. HBP-NH_2 played a crucial role as a reducing, stabilising, and binding agent. This study confirms the durability and effectiveness of AgNPs in textile applications. Nano-silver-treated fabrics hold great potential for medical and functional textile industries.

(Velmurugan *et al.,*2014) revealed that green-synthesized silver nanoparticles (AgNPs) provide strong antibacterial properties for textile and leather applications. These nanoparticles prevent bacterial adhesion, reducing odor and infection risks in shoes and socks. AgNPs penetrate bacterial membranes, disrupting cellular functions and ensuring prolonged antimicrobial activity. Their high surface area enhances effectiveness compared to bulk silver. A simple coating method allows easy integration into fabrics and leather. Further research is needed to optimize long-term performance for commercial applications.

2. Zinc Nanoparticles (ZnO NPs)

UV Protection: Absorb harmful UV rays, enhancing sun protection in outdoor and sportswear.

Self-Cleaning Textiles: Used in smart and functional clothing to reduce washing frequency.

(Fouda *et al.,*2018) revealed that biosynthesized ZnO nanoparticles (ZnO-NPs) offer effective antibacterial and UV-protective properties for medical textiles. Using *Aspergillus terreus* AF-1, ZnO-NPs were successfully synthesized without toxic chemicals, ensuring eco-friendliness. The nanoparticles exhibited strong antibacterial action, inhibiting *Staphylococcus aureus*, *Bacillus subtilis*, *Pseudomonas aeruginosa*, and *E. coli*. Cotton fabrics treated with ZnO-NPs showed over 82% bacterial inhibition and enhanced UV protection. These findings highlight ZnO-NPs' potential for safe and multifunctional textile applications. Further research is needed to refine their biocompatibility and long-term stability.

(Dejene *and* Geletaw 2024) state that green-synthesized ZnO nanoparticles (ZnO-NPs) offer eco-friendly self-cleaning properties for textiles. These nanoparticles enable physical, chemical, and biological self-cleaning, mimicking lotus leaf surfaces, degrading stains via photocatalysis, and exhibiting antibacterial effects against *S. aureus* and *E. coli*. ZnO-NPs effectively remove dirt, dyes, and liquids while maintaining environmental sustainability. Such textiles align with market demand for sustainable products with vast application potential. However, further research is needed to enhance their durability and comfort for long-term use.

3. Copper Nanoparticles (CuNPs)

Antiviral and Antimicrobial Effects: Effective against bacteria, fungi, and viruses, making them suitable for hospital textiles and PPE.

Conductivity: Used in smart textiles for wearable electronics and sensors.

(Sharaf *et al.,*2016) revealed that CuO-PANI-treated cotton fabric enhances conductivity and antibacterial properties. CuO ensures uniform PANI distribution, with CuO-pretreated samples showing the highest conductivity and superior antibacterial activity.

4. Gold Nanoparticles (AuNPs)

Biomedical Textiles: Incorporated into wound dressings for enhanced healing and biocompatibility.

Smart Textiles: Enable sensing and diagnostic applications due to their excellent conductivity.

(Silva *et al.,*2019) revealed that AuNPs-chitosan-coated soybean fibres exhibit strong antimicrobial properties, UV protection, and washing durability. XPS confirmed AuNPs binding to chitosan, suggesting antimicrobial action through oxidized Au species and reactive oxygen generation.

(Chan *et al.,*2016) revealed that AuNP-treated fabrics obey Ohm's law and hold potential for wearable sensors. Silk fabric showed promise as a chemical sensor for ethanol vapor detection. Further research is needed on fabric durability and broader chemical sensitivity. Future work aims to develop specialized sensing devices.

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International Journal of Environment, Agriculture and Biotechnology
Vol-10, Issue-3; May-Jun, 2025
Peer-Reviewed International Journal
Journal Home Page Available: https://ijeab.com/
Journal DOI: 10.22161/ijeab

Genetic Variability of Quantitative Traits in Indian Mustard (*Brassica juncea* L.) Germplasm Lines

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Received: 05 May 2025; Received in revised form: 03 Jun 2025; Accepted: 08 Jun 2025; Available online: 14 Jun 2025

Abstract *— The family Cruciferae (Brassicaceae) includes Indian mustard (Brassica juncea (L.) Czern & Coss), which is grown across India and the rest of the world under the genus Brassica. It contains 24% protein and 38–42% oil. Rai (B. juncea), a variety of mustard and rapeseed, is highly prized by farmers for its higher yield and stronger resistance to heat, relative diseases, lodging, shattering, drought circumstances, and saltwater sodic environments. In 50 genotypes of Indian mustard germplasm lines, an experiment was carried out to evaluate the genetic variability, correlation, and path analysis of twelve quantitative parameters. The experiment used a randomized block design with three replications. The analysis of variance ratios showed that the traits analyzed had highly significant differences among the genotypes. This indicates that there is considerable genetic variability among the Indian mustard germplasm lines for the quantitative traits under study. In conclusion, this study provides valuable insights into the genetic variability, heritability and genetic advance quantitative traits in Indian mustard germplasm lines.*

Keywords*— *Heritability, genetic advance, Genetic Variability.

I. INTRODUCTION

Brassica juncea L., is a globally consumed vegetable, oilseed, and condiment (Saleem *et al*., 2017). It appears that mustard is a Brassicaceae family member. Two amphidiploid species (2n = 36) of Indian mustard are found in nature: B. nigra (2n = 16) and B. rapa (2n = 20). Mustard, the most common kind of Brassica, is cultivated in between 85 and 90 percent of all oilseed fields globally (Rao et al., 2017). Indian mustard, a significant oilseed crop, has been cultivated for thousands of years in China, India, and more recently, Australia. Its primary growth regions in India include Madhya Pradesh, Gujarat, Haryana, Uttar Pradesh, and Rajasthan (Sharma et al., 2020).

The majority of Indian mustard plants are self-pollinating, however between 5 and 30 percent of their growth depends on environmental factors and unintentional diversity pollinating insects. Amphidiploid Indian mustard is produced by normal chromosomal multiplication following an intraopen cross between Brassica compestris (2n=20) and Brassica nigra (2n=16) (Shrimali et al., 2016).

The quantitative nature of mustard yield and its section would be useful in gaining knowledge about the type and intensity of hereditary change ability and its collaboration with climate. The relationship between circumstances and genotypes is especially interesting because, if inherited features are known and, for the most part, predictable in advance, they represent climate changes. Given this, it makes more sense to assess heritability while accounting for the entire range of variance by combining genotype and environment. This is because it permits choices that result in expectations of inherited development. "Cradled" OR uniform genotypes are those that can change their phenotypic state in response to ecological fluctuations and offer the best level of steady financial return (Allard and Bradshaw, 1964).

Genetic variety is essential in plant breeding; genetically distinct plants may be used in order to obtain the desired segregating generation recombination because hybrids between lines of diverse origins frequently exhibit more heterosis than hybrids between closely related strains. Genetic variability is crucial when developing an efficient

breeding programme for the enhancement of any crop species, such as Indian mustard. Germplasm, or the sum of diversity found in any crop species and relatives, is critical for exploitation in order to meet the majority of the shifting demands for improved crop types.

II. MATERIALS AND METHODS

During the 2022 Rabi season, the experiment was conducted in 50 genotypes at the Research Farm, Department of Agriculture, Mata Gujri College, Sri Fatehgarh Sahib, Punjab. Using a Randomized Block Design with three replications, fifty B. juncea genotypes were planted in the field with a 45 cm row-to-row spacing and a 15 cm plant-to-plant distance.

Five randomly selected plants were observed for twelve features, including days to first blooming, days to 50% flowering, Plant height (cm), number of siliqua per plant, number of seeds per siliqua, length of siliquae (cm), number of primary and secondary branches, days to maturity, biological yield (g), seed yield (g), and harvest index (%) are all included. Each character's test of significance was examined using the methods recommended by Panse and Sukhatme (1967).

Al-Jibouri et al. (1958) provided the formula for calculating the genotypic and phenotypic coefficients of variation, Burton and De Vane (1953) provided the broad definition of heritability (h2), and Johnson et al. (1955) proposed a procedure for calculating genetic advance, or the expected genetic gain.

III. RESULT AND DISCUSSION

3.1 Analysis of variance

Analysis of variance presented inclearly suggests that the significant differences among the genotypes for all traits indicating presence of significant genetic variability and diversity in the experimental material. All 12 variables, including days to first flowering, showed significant genotype differences, according to the analysis of variance. Plant height, number of siliquae/plants, siliqua length, number of seeds/siliquas, number of primary and secondary branches per plant, days to 50% flowering, and days to maturity. harvest index, biological yield, and seed yield/plant by Shekhawat et al. (2014) and Pant and Singh (2001).

3.2 Mean Performance

The highest and lowest mean performance of fifty genotypes for various characters has been described, and the results of these studies are presented is the appendix.

1. **Days to first flowering:** Mean value for 50 genotypes were ranging from **IC-589686** (65.00) to **Ashirwad** (82.00).
2. **Days to 50% flowering:** The average value of 50 genotypes were varies **from IC-571662** (74.00) to **IC-405235** (94.00).
3. **Days to maturity:** The average value of 50 genotypes were varies from **Jawahar Mustard** (121.00) to **IC-335852** (147.00).
4. **Number of primary branches per plant:** The mean value of 50 genotypes of mustard were varies from **IC-405235** (2.40) to **IC-311734** (9.40).
5. **Number of secondary branches per plant:** The mean value of 50 genotypes were ranging from **IC-405235** (6.00) to **IC-571678** (21.80).
6. **Plant height:** The highest and lowest mean performance of 50 genotypes were ranging from **IC-538719** (106.60) and **IC-599679** (170.40) respectively.
7. **Silquae count per plant**
8. : The mean value of 50 genotypes were ranging from for number of siliquae per plant is **IC-589686** (47.80) to **Navinder Roy** (492.40).
9. **Siliqua length:** The lowest and highest mean performance of 50 genotypes for siliquae length is **IC-589681** (3.14) and **IC-355856** (4.92).
10. The number of seeds in each siliqua**:** The mean value of 50 genotypes for number of seed per siliquae were ranging from **Geeta** (8.00) to **IC-571661** (20.00).
11. **Biological yield:** The mean value of 50 genotypes for biological yield per plant were ranging from **IC-589681** (10.94) to **IC-405235** (191.72).
12. **Harvest index:** The minimum and the maximum value of mean performance for 50 genotypes for harvest index is **IC-339953** (8.33) and **IC-599679** (54.48).
13. **Seed yield per plant:** The mean value of 50 genotypes for seed yield per plant were ranging from **IC-589681**(3.54) to **IC-571630** (49.32).

3.3 Variability and Genetic Parameters

Analysis of Variance demonstrated that for every character under study, the mean sum of squares resulting from genotypes was significant. Significant genetic variability is indicated by a very significant connection. The values of the phenotypic coefficient of variation (PCV), genotypic coefficient of variation, and environmental coefficient of variation are found in Table 1.1, which also presents estimates of the various genetic parameters. The data showed that, for the majority of de

min, PCV was more significant than GCV. The highest PCV and GCV values (194.29 and 172.87) were found in the number of siliquae per plant. For every seed quality criterion, the phenotypic coefficients of variation (PCV) were somewhat greater than the corresponding genotypic coefficients of variation due to environmental effect.

The identical outcomes were also reported by Chaudhary *et al.* (2003), Akabari and Niranjana (2015**),** Dilip et al. (2016), Srivastava *et al*. (2016) and Hyder *et al*. (2021). Similar results were found by Singh *et al.* (2018), Pant and Singh (2001), Shekhawat *et.al* (2014)**.**

3.4 Heritability Genetic advance

Heritability enhances selection effectiveness by separating experimental influence from total variability. The number of seeds per siliquae (95.83), days to 50% blooming (95.28), number of secondary branches (94.01), biological yield (89.64), harvest index (87.03), and siliqua length (82.64) were among the plant growth parameters where high heritability was noted. Singh (2004), Kumar and Misra (2007), and Yadava et al. (2011) all noted similar results. The high estimates of heritability values indicated that a considerable portion of the phenotypic variability for the feature in issue was heritable. Therefore, easy selection would be beneficial for increasing these traits.

According to the study, the number of siliquae per plant (104.77) had the greatest estimate of genetic advancement, followed by the number of secondary branches (101.73), the number of seeds per siliqua (91.45), the height of the plant (78.23), the biological yield (65.78), and the number of days of 50% blooming (63.48). The scope of improvement by simple selection was limited by the lowest estimates for the number of primary branches (5.66), siliquae length (7.21), and seed yield (7.27), as well as the number of days until first flowering (10.65). Additive gene activity is suggested by high heritability and genetic advancement in certain characteristics. Genetic advancement and moderate heritability, on the other hand, are controlled by both additive and non-additive gene activity but exhibit less environmental effect.

With variables like plant height and siliqua length exhibiting low heritability and genetic advance values, selection in succeeding generations may result in only little improvement. Singh et al. (2011) reported similar results. Additionally, all of these traits had substantial estimates of heritability. For several siliqua/plants, such high heritability along with high genetic advancement has been shown. Similar result has been reported by Singh *et al*. (2012) and Tiwari *et al*. (2016).

Table 1 Analysis of variance for yield and yield traits in 50 genotypes of Indian mustard (Brassica juncea L)

Source of Variation	DF	Days of first flowering	Days of 50% Flowering	No. of primary branches	No of Secondary branches	Plant Height (cm)	No. of Seeds/ siliquae	Siliquae length (cm)	No. of Seeds/siliquae	Days of Maturity	Biological yield/ plant (g)	Seed yield/ plant (g)	Harvest index (%)
Replication	2	154.94	60.927	55.553	1,691.96	37,443.98	86.087	86.717	86.087	2,388.29	499.457	25.254	17.968
Treatment	49	108.173	3,039.68	40.672	7,947.90	11,361.14	6,260.02	47.531	6,260.02	2,991.13	3,543.56	98.574	1,474.92
Error	98	8.239	49.355	6.093	165.191	2,796.84	89.59	3.11	89.59	290.699	131.434	24.361	69.789

Table 2 Estimation of different genetic parameters of variation for 12 traits among parents

Characters	Mean	Range		GCV(%)	PCV(%)	Heritability	GA	GA% mean
		Min	Max					
Days to first flowering	84.48	65.00	82.00	6.832	7.63	80.17	10.65	12.60
Days to 50% flowering	22.15	74.00	94.00	142.55	146.04	95.28	63.48	286.66
Primary Branches Number	12.89	2.40	9.40	26.34	32.56	65.42	5.66	43.88
Secondary branches Number	118.78	6.00	21.80	42.88	44.22	94.01	101.73	85.65
Plant Height (cm)	187.67	106.60	170.40	28.47	40.057	50.51	78.23	41.68
No. of Siliquae/ plant	33.06	47.80	492.40	172.87	194.29	79.17	104.77	316.86
Siliquae length (cm)	12.24	3.14	4.92	31.43	34.57	82.64	7.21	58.86
No. of Seeds / siliquae	108.89	8.00	20.00	41.65	42.54	95.83	91.45	83.99
Days of Maturity	97.25	125.00	137.33	30.85	35.48	75.59	53.73	55.25
Biological yield/ plant	30.78	42.61	150.98	109.55	115.70	89.64	65.78	213.67
Seed yield/ plant	18.83	8.85	40.54	26.41	37.21	50.38	7.27	38.62
Harvest index (%)	63.68	9.97	33.03	33.99	36.43	87.03	41.59	65.31

IV. CONCLUSION

The results of present study indicated that ample amount of genetic variability present in the material. The mean performance of 50 genotypes for various characters was analysed, highlighting the highest and lowest mean performances across different traits. The coefficient of variation was used to indicate the extent of variability present for these traits. Analysis of genetic parameters revealed that in most cases, the broad sense heritability (PCV) had a higher effect compared to the narrow sense heritability (GCV). Traits such as number of siliquae per plant, days to 50% flowering, biological yield, number of secondary branches per plant, number of seed per siliqua, plant height, seed yield per plant, harvest index, days to maturity, siliqua length, number of primary branches per plant, and days to first flowering exhibited the highest values of PCV and GCV.

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International Journal of Environment, Agriculture and Biotechnology
Vol-10, Issue-3; May-Jun, 2025
Peer-Reviewed International Journal
Journal Home Page Available: https://ijeab.com/
Journal DOI: 10.22161/ijeab

Impact Assessment of Pre and Post Disaster Management Awareness Training Programme Conducted by WASH (Women Association for Sustainability & Harmony) - NGO in Cuddalore District

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Received: 08 May 2025; Received in revised form: 05 Jun 2025; Accepted: 11 Jun 2025; Available online: 16 Jun 2025

Abstract— *This study evaluates the impact of the Disaster Management Awareness Training Programme (DMATP) conducted by the Women's Association for Sustainability and Harmony (WASH), a Cuddalore-based NGO, under the Aapda Mitra initiative of the National Disaster Management Authority. The program aimed to strengthen community resilience by equipping volunteers with skills in disaster preparedness, risk assessment, and emergency response. Using a pre- and post-training assessment framework, the study employed quantitative tools including paired T-tests and Pearson's correlation to measure changes in participants' knowledge, preparedness levels, and adaptive capacity. A sample of 30 volunteers was selected through proportionate random sampling from three training batches. Data were collected via structured interviews and analysed using percentage analysis, frequency distribution, and inferential statistics. The results showed a statistically significant improvement in post-training knowledge (mean difference: - 6.667, p = 0.000), confirming the program's effectiveness. Participants demonstrated improved understanding of disaster risks, first aid, —evacuation planning, and community coordination. Demographic analysis indicated 56.7% of participants were female, suggesting strong gender-inclusive engagement. The majority were middle- aged (63.3%), college- educated (70%), and from medium-income households (80%). However, challenges such as limited accessibility to training content and concerns over long-term knowledge retention were identified. Correlation analysis revealed that extension agency contact (r = 0.177) had a positive impact on training outcomes, whereas information-sharing behaviour (r = -0.280) showed a negative correlation, indicating a need to strengthen communication channels post-training. In conclusion, the WASH-led DMATP significantly enhanced community-level disaster resilience. The study recommends sustained follow-up through mock drills, refresher training, and policy-level integration to ensure long-term impact. These findings provide valuable insights for policymakers, NGOs, and disaster management practitioners focused on community-based disaster risk reduction in vulnerable regions.*

Keywords— ***Disaster Management, Community Resilience, Aapda Mitra, Awareness Training, Preparedness, Adaptive Capacity, WASH NGO, Impact Assessment, Gender Inclusion, Cuddalore.***

I. INTRODUCTION

Disaster preparedness at the community level has emerged as a critical component of effective disaster risk reduction, especially in vulnerable regions like coastal Tamil Nadu. Recognizing the need for localized resilience-

building, the National Disaster Management Authority (NDMA) launched the Aapda Mitra programme to train community volunteers in disaster preparedness and emergency response. Implemented across all states and union territories of India, this initiative has focused on developing a structured network of first responders, particularly in high-risk districts.

In Tamil Nadu, the program has been rolled out in 16 disaster-prone districts, including Cuddalore, where frequent cyclones, floods, and coastal hazards threaten lives and livelihoods. The Women's Association for Sustainability and Harmony (WASH), a Cuddalore-based NGO established in 2000, has taken a leading role in executing the training in the region. With a mission centered on gender inclusiveness, community development, and disaster resilience, WASH has mobilized and trained local volunteers through this initiative.

The Aapda Mitra training programme covers key domains such as risk assessment, evacuation planning, first aid, rescue operations, emergency communication, and post-disaster rehabilitation. Through mock drills, simulation exercises, and capacity-building sessions, it aims to equip volunteers with essential life-saving skills and enhance their role in managing localized emergencies.

Despite the program's wide implementation, there is a notable lack of empirical studies evaluating its effectiveness. In particular, limited research exists on whether such training improves participants' disaster knowledge, preparedness levels, and adaptive capacity. This study seeks to fill that gap by analyzing the impact of the Aapda Mitra training delivered by WASH in Cuddalore district.

By employing a pre- and post-training assessment framework, this research evaluates changes in knowledge and preparedness among community volunteers. The findings offer valuable insights into the program's impact and inform strategies for improving grassroots disaster response. The study also explores demographic characteristics, communication linkages, and extension contact to understand the variables influencing training outcomes, thereby contributing to the broader discourse on community-based disaster management in India.

II. MATERIALS AND METHODS

Locale of the Study

The research was conducted in Kumaratchi Grama Panchayat, Kumaratchi block, in Cuddalore District, Tamil Nadu. The area was chosen based on its vulnerability due to socio-economic disadvantages, and environmental risks such as flooding and saltwater intrusion.

Selection of District and NGO

Cuddalore District, with its extensive coastline, is prone to natural disasters like cyclones and tsunamis. The district was selected for its historical exposure to hazards and the availability of vulnerability maps under the Integrated Coastal Zone Management Plan (ICZMP). WASH NGO was selected as the sole organization offering disaster preparedness training in Cuddalore. With experience training 300 volunteers, WASH plays a critical role in building community resilience.

Sampling and Selection of Respondents

From a total of 300 volunteers trained across three batches, 30 were selected using proportionate random sampling (10 per batch). The selection formula was:

$$ni = (Ni / N) \times n$$

Where:

- ni = number of respondents from the i-th batch
- Ni = total volunteers in the i-th batch
- N = total trained volunteers (300)
- n = sample size (30)

Variables and Measurement

The two dependent variables measured were the pre-training and post-training knowledge levels.

Pre Level Questions	Score	Post Level Questions	Score
YES	1	YES	1
NO	0	NO	0

Constraints Faced by Volunteers

Challenges reported included limited training content, financial accessibility issues, and variability in information retention. However, most volunteers acknowledged improved awareness and confidence in disaster response.

Data Collection Method

Data were collected in December 2024 using a structured interview schedule developed and pre-tested for clarity. Interviews were conducted in-person to ensure accurate and comfortable data gathered.

Statistical tools to be used :

The data collected were analyzed using several statistical tools to ensure accurate interpretation and robust evaluation of the training programme. Frequency analysis was employed to determine how often each response occurred within the dataset. Percentage analysis was used to express the frequency of responses as a proportion of the

total sample size, calculated using the formula:

(Category Frequency / Total Frequency) × 100.

To assess the effectiveness of the training, a paired t-test was applied to compare the mean scores of participants' knowledge before and after the training. The formula used was:

$$t = \bar{d} / (sd / \sqrt{n}),$$

where $\bar{d}$ = mean of differences, sd = standard deviation of differences, n = sample size.

Additionally, Pearson's correlation coefficient (r) was used to evaluate the strength and direction of the relationship between selected independent variables (such as age, education, income, and extension contact) and the training outcomes.

$$r = [n(\sum xy) - (\sum x)(\sum y)] / \sqrt{\{[n\sum x^2 - (\sum x)^2][n\sum y^2 - (\sum y)^2]\}}$$

These tools provided a comprehensive statistical framework to measure changes in disaster preparedness and knowledge levels among participants, and to determine the influence of demographic and behavioral factors on training effectiveness.

III. FINDINGS AND DISCUSSION

This study evaluated the impact of the Disaster Management Awareness Training Programme (DMATP) conducted by WASH in Cuddalore district. Data collected from 30 participants through structured interviews were analyzed using frequency, percentage, paired t-test, and Pearson's correlation to address two key objectives: understanding the profile characteristics of the respondents and assessing the changes in their knowledge, preparedness, and adaptive capacity before and after the training.

In terms of profile characteristics, the study found that 56.7% of the respondents were female, highlighting strong women participation in disaster preparedness efforts. A majority (63.3%) of the participants were from the middle-age group (36–45 years), indicating active engagement from this demographic. Educationally, 70% had completed collegiate-level education, while 30% had completed higher secondary school, suggesting that well-educated individuals were more likely to participate in the program. Income analysis showed that 80% of respondents belonged to the medium-income group (₹1.3 to ₹2.5 lakh per annum), reflecting higher participation from this socioeconomic bracket. Regarding extension agency contact, 54% had occasional interaction, 18% had frequent contact, and 28% had no contact at all, indicating moderate engagement with support agencies. While 41% of participants were not affiliated with any organization, 30% were members and 29% held leadership roles. Information sharing behavior was active among 53% of respondents, with 30% sharing sometimes and 17% never sharing information.

The pre-training assessment revealed a lower level of disaster-related knowledge and preparedness, with a mean difference of -6.667, standard deviation of 2.155, and standard error of 0.393. Post-training scores showed significant improvement, with a p-value of 0.000, confirming the training's effectiveness. A paired t- test yielded a t-value of -16.945 (df = 29), and the confidence interval (-7.471 to -5.862) confirmed a statistically significant increase in post-training knowledge and skills.

Correlation analysis revealed that organizational participation (r = 0.252) had the highest positive correlation with post-training outcomes, followed by gender (r = 0.166) and education (r = 0.124). Conversely, extension agency contact (r = -0.234) and information sharing behavior (r = -0.218) were negatively correlated with post-training outcomes, indicating that higher levels of these variables did not necessarily translate to improved performance. Age (r = 0.030) and annual income (r = -0.005) showed negligible influence. Additionally, significant inter-variable correlations were observed between education and extension contact (r = 0.399), and between information sharing and extension contact (r = 0.380), suggesting interaction effects between background variables.

In summary, the training program significantly enhanced participants' disaster preparedness and adaptive capacity. While education and organizational involvement positively influenced outcomes, variables like age and income were less impactful. These findings underscore the importance of structured, inclusive training programs and the need for targeted outreach to ensure broader community engagement in disaster risk reduction.

IV. CONCLUSION

The impact assessment of the Disaster Management Awareness Training Programme (DMATP) conducted by WASH NGO demonstrates the effectiveness of structured community education in improving disaster preparedness. Pre-training evaluations revealed low baseline awareness and limited knowledge of disaster risk reduction techniques, emphasizing the vulnerability of untrained communities. Post-training results showed statistically significant improvements, with a negative mean difference of -6.667 and a p-value of 0.000, validating the program's effectiveness. Participants gained essential knowledge in emergency response, risk assessment, and

early warning systems, and reported greater confidence in disaster readiness. The training's participatory approach encouraged practical engagement, making the learning both impactful and sustainable. However, long-term resilience requires continued reinforcement through refresher training, mock drills, integration of DRR into policy and education, and regular follow-up assessments. The initiative sets a model for localized disaster preparedness, proving that empowering communities through targeted training can lead to measurable and meaningful improvements in resilience and safety.

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International Journal of Environment, Agriculture and Biotechnology
Vol-10, Issue-3; May-Jun, 2025
Peer-Reviewed International Journal
Journal Home Page Available: https://ijeab.com/
Journal DOI: 10.22161/ijeab

Relationship between independent variables and Technological gap among coconut growers

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Received: 28 Apr 2025; Received in revised form: 23 May 2025; Accepted: 27 May 2025; Available online: 03 Jun 2025

Abstract— *The current investigation or study was done in the district called Tumkur district of Karnataka during the year 2022–23, using an ex-post-facto research design to explore the factors influencing the technological gap in coconut cultivation. Purposively Tumkur was chosen due to its prominence as a major coconut-producing region in the state. From the ten taluks in the district, four taluks namely Tiptur, Turuvekere, Chikkanayakanahalli, and Sira were chosen based on differences in productivity levels. A total of 120 coconut growers, with 30 from each selected taluk, were randomly sampled for the research or study. Correlation was utilized to identify significant relationships between the selected dependent variable and variables called as the independent variables. Thus, in the relationship study between independent variables and the technological gap, it was disclosed that education, information seeking behaviour, extension participation, credit orientation, innovativeness, deferred gratification, scientific orientation and cosmopoliteness were seen to be negatively related with technological gap at one per cent significant or significance level whereas the management orientation and risk orientation seen to be negatively related with technological gap at five per cent significant or significance level while age, family size, land holdings and farming experience were found to have non-significant relationship with the technological gap.*

Keywords— ***Coconut growers, Independent variables, Relationship, Technological gap, Tumkur***

I. INTRODUCTION

In the context of agricultural development, the adoption of recommended technologies plays a crucial role in enhancing productivity and ensuring sustainable farming practices. Despite the availability of advanced cultivation methods, a considerable gap often exists between what is recommended and what is actually practiced by farmers. This disparity, referred to as the technological gap, can significantly impact crop yield and resource efficiency. Understanding the underlying factors contributing to this gap is essential for designing targeted interventions and improving the adoption of innovations. Coconut farming, being a vital component of the agrarian economy in several regions, particularly in Karnataka, has shown considerable potential for growth. However, many coconut growers continue to face challenges in fully implementing scientific cultivation practices. Various socio-economic, psychological and communication-related factors may influence a farmer's ability and willingness to adopt new technologies. By examining the relationship between such independent variables and the existing technological gap, researchers and policymakers can gain insights into the constraints and motivations that drive farmer behavior. This study aims to identify which farmer-related factors are significantly associated or having relationship with the technological gap in coconut cultivation. Such an analysis is critical for formulating appropriate extension strategies and policy measures that can bridge this gap, thereby promoting more effective and widespread adoption of improved farming techniques, thereby improving the socio-economic status of the coconut growers.

II. MATERIALS AND METHODS

The current investigation or study was done in the district called Tumkur district of Karnataka during the year 2022–23, employing an ex-post-facto research design. Tumkur was deliberately selected as the study area due to its prominence in coconut cultivation across several of its taluks, making it one of the leading coconut-producing districts in the state. Based on variations in productivity levels, four taluks—Tiptur, Turuvekere, Chikkanayakanahalli, and Sira—were purposively chosen from the ten taluks within the district. From each selected taluk, thirty coconut farmers were randomly chosen using a simple random sampling technique, resulting in a total sample size of 120 coconut growers. Fourteen attributes like the Age, Education, Family size, Land holding, Farming experience, Information seeking behavior, Extension participation, Management orientation, Risk orientation, Credit orientation, Innovativeness, Deferred gratification, Scientific orientation and Cosmopoliteness were selected as independent variables in the study and Technological gap was selected as one of the dependent variables in the study. Technological gap refers to the difference between the recommended technology and the actual technology used by the coconut growers at field level (Nagaraj, 1999) [2]. Then the correlation was used to know the significant relationship between these dependent and independent variables.

III. RESULTS AND DISCUSSION

3.1 Relationship between independent variables and Technological gap among coconut growers

Among the relationship or association between variables called as the independent variables and the technological gap shown in table 1, it was found that education, information seeking behaviour, extension participation, credit orientation, innovativeness, deferred gratification, scientific orientation, cosmopoliteness were negatively related with technological gap at one per cent level of significance, whereas the management orientation, risk orientation were negatively related with technological gap at five per cent level of significance. This indicates that as these variables decreased the technological gap increased leading to higher gap in taking up the recommended cultivation practices in coconut farming while age, family size, land holdings, farming experience were non-significant with respect to technological gap meant that these variables had no contribution towards the existing technological gap among the coconut growers. In a similar study by Patel and Padheria (2010) [4], it was revealed that there was non-significant relationship between age and technological gap of Safflower growers. Another similar study by Neha (2014) [3], revealed that there was non-significant relationship between family size and technological gap of rose growers and there was non significant and negative association or relationship between land holding and technological gap of rose growers.

Education: The negative relationship between education and the technological gap suggests that lower levels of education among coconut growers are associated with an increased technological gap. Less educated individuals might have poor access to information, be less open to innovation, and have less problem-solving skills, discouraging them unable to adopt new technologies more readily. A similar study by Jadhav (2009) [1], observed that there was negatively and significant relationship between education and technological gap of mango growers. Another study by Patel and Padheria (2010) [4], revealed that there was negatively and significant association or relationship between education and technological gap of Safflower growers. One more similar study by Neha (2014) [3], revealed a finding that there was negative and highly significant relationship between variable called education and technological gap of rose growers.

Information Seeking Behavior: A negative correlation between information seeking behavior and the technological gap implies that growers who are less active to seek out information are likely to have a more technological gap. Less information seekers are less likely to be aware of advancements, best practices, and market trends, which can increase the gap towards modern agricultural practices.

Extension Participation: Extension services provide valuable information and training, enabling coconut growers to enhance their knowledge, attitude and skills, which in turn can reduce the technological gap. But the negative relationship between extension participation and the technological gap suggests that those who might not engage with agricultural extension services are less likely to adopt new technologies. A similar study by Jadhav (2009) [1], observed that there was negatively and significant relationship between extension participation and technological gap of mango growers.

Credit Orientation: As the credit orientation found medium to low among the coconut growers which showed that there was negative correlation between credit orientation and the technological gap implying that growers who are less willing to use credit are not positioned well to invest in new technologies.

Innovativeness: The negative association between innovativeness and the technological gap indicates that

coconut growers are less open to innovation which might contributed to their existing technological gap.

Deferred Gratification: The negative relationship between deferred gratification and the technological gap suggests that individuals who neglect long-term benefits over immediate gains are less likely to invest in modern technologies.

Scientific Orientation: The negative correlation between scientific orientation and the technological gap implies that medium to low scientific orientation might contributed to the found technological gap. A similar study by Neha (2014) [3], revealed that there was negative and significant association or relationship between scientific orientation and technological gap of rose growers.

Cosmopoliteness: The negative association between cosmopoliteness and the technological gap suggests that the medium level of cosmopoliteness might have influence with the technological gap.

Table 1: Relationship between independent variables and Technological gap among Coconut growers (n=120)

Sl. No.	Independent variable	Correlation co-efficient (r)
1	Age	-0.98NS
2	Education	-0.235**
3	Family Size	-0.054NS
4	Land-holdings	-0.155NS
5	Farming experience	-0.004NS
6	Information seeking behaviour	-0.408**
7	Extension participation	-0.382**
8	Management orientation	-0.184*
9	Risk orientation	-0.232*
10	Credit orientation	-0.243**
11	Innovativeness	-0.363**
12	Deferred gratification	-0.327**
13	Scientific orientation	-0.257**
14	Cosmopoliteness	-0.334**

*=5% level of significance, **=1% level of significance and NS=Non-significant

Management Orientation: Lower management orientation of the coconut growers may have contribution towards the higher technological gap among the coconut growers.

Risk Orientation: The negative correlation between risk orientation and the technological gap implies that those who are less willing to take risks are less positioned to adopt innovative technologies.

IV. CONCLUSION

The findings of the study highlight that certain personal, psychological and behavioral characteristics of farmers play a significant role in influencing the technological gap in coconut cultivation. This indicates that significant levels of these factors are associated with technological gaps, suggesting that farmers who are more informed, innovative and outward-looking are more likely to adopt recommended cultivation practices. By addressing these key influencing factors, policymakers and extension agencies can work more effectively to reduce the technological gap and promote the adoption of improved agricultural practices in coconut farming.

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International Journal of Environment, Agriculture and Biotechnology
Vol-10, Issue-3; May-Jun, 2025
Peer-Reviewed International Journal
Journal Home Page Available: https://ijeab.com/
Journal DOI: 10.22161/ijeab

Rainfall and Temperature Projection Analysis and Their Relation to The Potential Harvest Amount of Maize (Zea mays L.)

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Received: 18 May 2025; Received in revised form: 12 Jun 2025; Accepted: 17 Jun 2025; Available online: 21 Jun 2025

Abstract— *Maize is one of the commodities used as a source of food for the Indonesian people besides rice. Maize is also often used as an industrial raw material, food or feed. Maize productivity in Indonesia in 2023 decreased by 0.07 tons/ha or 0.5% compared to the productivity in 2022 of 14.08 tons/ha. East Java Province is the region with the highest production in Indonesia. East Java contributes about 25.60 percent of Indonesia's total production. One of the problems in corn production is climate change. Climate change affects the agricultural sector with extreme changes in rainfall and temperature. Rainfall and temperature can affect evapotranspiration in determining crop water requirements. Water requirements can affect the quality and quantity of crop production. Therefore, it is necessary to conduct strategic mitigation and adaptation based on the possibility of climate change that occurs in the future using climate projection scenarios. The climate scenario used is Representative Concentration Pathways (RCP). The purpose of this study is to project the increase in rainfall and temperature in Tuban district and Malang district based on the RCP scenario and its relationship with the potential yield of maize. This research was conducted in December - January 2025. The research locations taken were Tuban Regency and Malang Regency. The research was conducted using descriptive analysis method. The research location used purposive sampling method based on consideration according to the required criteria, namely lowlands and midlands. The data used in this study are monthly rainfall projection data, minimum temperature, maximum temperature and average temperature. In addition, there are also longitude and latitude data, root depth, deplection fraction, pan evaporation, crop coefficient and correction factor. Climate projection scenario data is used with the Representative Concentration Pathways (RCP) 4.5 and 8.5 scenario models REG CM 4 and CSIRO MK 3.6. The results showed that rainfall and temperature projections as well as irrigation needs and potential crop yields showed that projections using RCP 8.5 showed a higher increase compared to RCP 4.5 which tended to experience stable fluctuations. In the rainfall projection, Malang Regency tends to experience a higher increase than Tuban Regency. Meanwhile, the temperature projection of Tuban Regency tends to show a higher increase compared to Malang Regency. Irrigation water demand in both regions tends to increase in August and September. Meanwhile, potential crop yields in both regions are projected to decline where Tuban Regency is more vulnerable to a higher yield decline compared to Malang Regency due to lower rainfall.*

Keywords— ***Climate projection, Maize, Climate change, Irrigation water demand, Potential crop yield.***

I. INTRODUCTION

Climate change is an issue that occurs almost all over the world. Climate change is caused by increasing greenhouse gas emissions, triggering global warming (Widiarta, 2016). The impact of climate change is greater in tropical areas, especially Indonesia, such as global temperature increases, rising sea levels, shifting rainfall patterns and causing increased extreme rainfall[1]. This phenomenon has a major impact on several sectors in Indonesia, especially the agricultural sector. The impact of changes in rainfall patterns and temperatures that most affect plant productivity. Changes in rainfall patterns and temperatures can result in increased pest and disease attacks, which can reduce farmer productivity and income. Food crops are one of those that have an impact both in terms of quality and quantity, especially corn. Corn is one of the staple commodities used as a source of food for the Indonesian people besides rice. Corn is a plant that is included in the cereal group which has economic and strategic value so that there is an opportunity to be developed as a source of carbohydrates after rice [1]. Feed and industrial needs dominate around 50% of national corn needs, so that corn production must be increased both through increasing corn productivity and expanding planting areas. According to the Center for Agricultural

Data and Information Systems (2024), the volume of corn exports in Indonesia decreased in 2022 by 237,386 tons and in 2023 by 180,257 tons, while the volume of imports increased in 2022 by 1,311,064 tons and in 2023 by 1,354,187 tons. Corn plant productivity in Indonesia in 2023 decreased by 0.07 tons/ha or 0.5% compared to productivity in 2022 of 14.08 tons/ha (Directorate General of Food Crops, 2023). East Java Province is the region with the highest production in Indonesia. East Java contributes around 25.60 percent of the total corn production in Indonesia [1]. One of the regions with the largest production is Tuban Regency is also a center for corn production in East Java Province and is included in the lowland area. In addition, Malang Regency is one of the corn producing areas in the middle plains. In the cultivation of food crops, especially corn, there are several environmental factors that play a major role in plant growth, such as altitude. Corn plants are plants that are easily adaptable and can grow in lowlands to highlands. Different altitudes will trigger differences in quality and quantity in plants and affect plant growth and development [1].

Corn is a plant that is sensitive to high and extreme temperatures, especially during flower formation [2]. These extreme temperature changes can result in a decrease in the quality and quantity of the corn plants produced. Temperature and rainfall are factors that can affect evapotranspiration. Evapotranspiration in agriculture can function in determining the water needs of plants or determining planting patterns that are appropriate for the area to be planted. This water requirement can affect the quality and quantity of plant productivity [3]. This water requirement calculation is used to plan the amount of water needed by plants as well as the right time and planting period according to the plant growth phase. Therefore, in dealing with these problems, strategic mitigation and adaptation are needed based on the possibility of climate change that will occur in the future using climate projection scenarios. Scenarios allow for analyzing and studying the consequences faced in the long term and exploring the possibilities that may occur in the future [4]. In this case, scenarios are carried out to predict climate change that will occur in the future. In the process of predicting climate, several experts use a climate prediction model called climate data projection or Climate Projection Modeling [5]. This model aims to predict the possibilities that will occur in the future and can analyze the possible causes. One of the climate models that is often used is the Representative Concentration scenario Pathways. RCP focuses on atmospheric greenhouse gas concentrations, energy use, radiative effects, land use and temperature anomalies based on time. This scenario also includes 4 trends based on the development of greenhouse gas emissions, namely a scenario with close mitigation (RCP 2.6), an intermediate scenario (RCP 4.5 and RCP6.0) and a scenario with high greenhouse gas emissions (RCP8.5) [6]. This study was conducted to project increased rainfall and temperature using two different scenarios in corn production areas representing lowlands and midlands. The scenarios used are RCP 4.5 as a pessimistic scenario (intermediate scale) and RCP 8.5 as an optimistic scenario (high scale).

II. LITERATURE REVIEW

A. Corn Plant

Corn (Zea mays L.) is a type of plant that is classified as a grain food crop that also comes from the grass family and is one of the important carbohydrate-producing plants in the world besides rice and wheat (Sulaiman et al., 2018). Corn is a plant that has one house (monoecious) because the location of female flowers with male flowers is separate but still on the same plant. Corn is a C4 plant that can adapt to growth limiting factors and corn is also susceptible to low sunlight because it can affect the growth of corn plants (Syafruddin et al., 2014). Corn plants have three types of roots, namely seminal roots, adventitious roots and hook roots (Fiqriansyah et al., 2021). Seminal roots are roots that develop from the radicle and embryo.

Corn plants have stem segments with variations of 10-40 segments. The stem segments are usually round, flat

at the bottom and cylindrical at the top and have no branches. Corn stalks are about 2-2.5 meters long and have several types and varieties (Sulistiana and Ilyas, 2022). Corn plant node nodes have shoots that can develop into cobs, while the top two shoots will develop into cobs. Corn stalks have 3 main tissues including skin tissue (epidermis), stem center (pith) and vascular tissue (vascular bundles) (Fiqriansyah et al., 2021). Corn has strong stems and many layers of thick-walled sclerenchyma tissue under the stem and around the vascular bundles. The thickness of the skin varies which can be used as a selection of plant tolerance to stem lodging.

Corn plants are plants that originate from tropical areas. Corn usually grows in areas located between 0o-50o North Latitude to 0o 40o South Latitude. These areas are areas with moderate to wet subtropical climates. Corn grows in places with full sunlight. Corn can grow in all seasons depending on the availability of sufficient water. The rainfall needed by corn plants to grow is between 200-800 mm per month (Riwandi et al., 2014). The best time to plant corn is at the start of the dry season and at the beginning of the rainy season. The appropriate altitude for corn growth is between 0-1300 meters above sea level with an optimal temperature of 23-27 oC (Hitijahubessy et al., 2016). Corn growth really needs full sunlight because shaded corn plants can inhibit growth and the seeds produced are not good or cannot even form cobs. Corn plants in their growth require an average temperature of 24 OC with a minimum temperature between 8-10 OC and a maximum temperature above 40 OC. At the time of seed germination, a temperature of 25 OC is a temperature that can accelerate the process, while temperatures above 40 OC can inhibit plant germination.

B. Climate Change and Its Impact on Increases and Decrease in Rainfall and Temperature

Climate change is one of the phenomena that is currently threatening human life. Over the last century, the phenomenon of global warming has become an important issue, especially in global governance or development policies (Rasmikayati and Djuwendah, 2015). Global warming occurs due to human activities. Human activities such as the use of fuel, natural gas, coal and petroleum. For example, the use of fuel in vehicles that can produce carbon dioxide or other gases such as Methane ($CH4$), water vapor ($H2O$), Nitrous Oxide ($N2O$), Chloro Fluoro Carbon (CFC), Ozone ($O3$) which are called greenhouse gases (Ainurrohmah and Sudarti, 2022). This phenomenon occurs due to increased greenhouse gas emissions into the atmosphere. These greenhouse gases can trap the sun's heat in the atmosphere and can cause climate instability and increased temperatures (Hariyono and Rochadi, 2024). The continuation of greenhouse gases can cause long-term changes in climate conditions and further warming. These impacts can be widespread and increasingly severe so that they cannot be controlled by humans or ecosystems (UNCTAD, 2016). Extreme climate conditions have increased, marked by increased climate variability in the last thirty years.

Climate change will continue to increase if human activities that cause global warming cannot be reduced. Climate change is already in a critical phase. Where in this phase it is likely to be very difficult to overcome the impacts of climate change. Climate change can have an impact on several aspects of human life. The agricultural sector is one of the sectors affected because it is the source of the economy that contributes the most to some of the Indonesian people (Syakir and Surmaini, 2017). Climate is the most influential factor in agriculture. Climate change can have an impact on plant physiology which also affects plant growth and production (Timotiwu et al., 2021). This impact is caused by the highest increase in temperature so that the photosynthesis process can be disrupted. Climate change can have an impact on increasing extreme climates such as the frequency of El-Nino and La-Nina which also increases. El-Nino can cause drought due to the long dry season, while La Nina has an impact with an increase in high rainfall which can result in excess water or flooding (Widiarta, 2016). Climate change also affects the characteristics of rain and the duration of the rainy season which is getting shorter, while the dry season period is getting longer. This has an impact on the number of rainy days decreasing and the intensity of rainfall and maximum daily rainfall increasing (Yasa et al., 2024).

C. The Effect of Rainfall and Temperature on Corn Plant Productivity

Climate is one of the important resources for plant productivity. Climate elements that can affect plant productivity are rainfall and temperature. Increased temperature and rainfall due to global warming can threaten food security and agricultural production (Li et al., 2019). The rainfall conditions in an area are an important factor in plant growth. Rainfall is the accumulation of rainwater that falls in a period with a certain time unit (Ruswanti, 2020). Unstable or changing rainfall can cause problems such as extreme rainfall can cause flooding or low rainfall can experience drought. The impact of climate change such as changes in unpredictable rainfall has a major impact on the agricultural sector. This is because the agricultural sector is very dependent on water, especially rainwater (Ruminta, 2016).

This impact can also occur in plant metabolism, potentially leading to decreased production or crop failure.

The variability of rainfall in Indonesia results in shifts in the rainy and dry seasons. The increase in the frequency of severe climate change can cause an increase in abiotic and biotic stress on plants (Syakir and Surmaini, 2017). Drought is the leading cause of crop failure due to climate change. The impact of climate change is also directly seen from the increasing attacks of pests and diseases. Armyworm (Spodoptera frugiperda) is one of the pests that often attacks corn plants in high rainfall conditions. Corn growth is greatly influenced by rainfall, especially if there is no adequate drainage. This can result in crop failure because the roots of corn plants are susceptible to excess water conditions. According to Sirait et al. (2020), corn plants that experience excess water can result in a decrease in production of around 30-50% compared to normal conditions.

The instability of rainfall and temperature conditions in Indonesia can disrupt the quality or quantity of plants. According to the Intergovernmental Panel on Climate Change (2014), a projection of temperature increase in the 21st century will reach 20C if there are no preventive measures. This increase in temperature can have several adverse effects on plants, especially food crops. High temperatures can also result in the availability of water for plant growth being unfulfilled. Increased air temperature caused by climate change can disrupt the photosynthesis process to the respiration process in plants, thereby inhibiting plant productivity (Anripa et al., 2023). Increased temperature in the increasingly high environment can cause transpiration so that plants need more water to evaporate due to adaptation to the high temperature environment. This change can affect the photosynthesis process of plants (Garunna et al., 2014). Disrupted photosynthesis can also disrupt plant productivity.

D. Climate Projections

Projection is an estimate of future conditions using existing data. Climate projection is a picture of future climate seen based on changes in greenhouse gas (GHG) composition (Suryadi et al., 2017). A picture of future climate conditions is often referred to as a scenario. Scenarios emphasize understanding the future climate picture and the uncertainty in responding to changes in greenhouse gas emissions and do not predict them (Kusumo and Septiadi, 2016). This climate projection is arranged based on emission scenarios that continue to occur until now. This scenario is assessed based on emission control factors that influence the increase in GHG concentrations in the atmosphere (Surmaini and Faqih, 2016). This can also affect the magnitude of Radiative Forcing (RF, units of W m-2). This RF is the amount of radiation energy that changes when entering and exiting the troposphere layer which is considered to have damaging interference from the radiation energy pattern (Adhayani et al., 2019).

Scenarios based on changes in RF values are the input used to project various changes in climate elements. This information is studied in a global climate model. The Global Circulation Model (GCM) is a global climate model that is widely used in reporting projections of future climate variations (Zhang et al., 2021). The data produced is in the form of a grid region or grid with a resolution of around 2.5 ° or ± 300 km2 that represents the global climate conditions. On a regional scale, a regional climate model (Regional Climate Model) is used to obtain information with higher resolution. The scenario used is called Representative Concentration Pathways (RCP). This RCP can represent the entire estimated range of future RF flows. In this scenario, there are four scenarios that are described from the lowest optimistic to the highest pessimistic. Based on the RCP scenario, there are four different tendencies in the development of greenhouse gas emissions consisting of a strict mitigation scenario (RCP2.6), an intermediate scenario (RCP4.5 and RCP6.0), and a scenario with high greenhouse gas emissions (RCP8.5) (Bienvenido-Huertas et al., 2021). In this study, RCP 4.5 and RCP 8.5 were used. RCP 4.5 represents annual greenhouse gas emissions with a peak around 2040 and a decline in the 21st century, while RCP 8.5 represents a continuous increase in greenhouse gas emissions throughout the 21st century (Yao et al., 2019). The scenario model used can project climate conditions up to 2100.

Research using the Representative Concentration Pathways scenario has been widely conducted, especially in the agricultural sector. One example of research conducted by Fajrianti (2024) which discusses the influence of climate projections on rainfall elements on rice plant productivity until 2045. The scenarios used in this study were RCP 2.6 and RCP 8.5 with 3 different models, namely MOHC-HadGEM2-ES, MPI-M-MPI-ESM-MR and NCC-NorESM1-M. The results of this study show an increase in rice plant productivity in 2045 in the RCP 2.6 scenario and a decrease in rice plant productivity in Malang and Banyuwangi Regencies. In addition, scenario 2.6 shows a relatively stable increase in rainfall and RCP 8.5 shows more extreme rainfall variations.

E. The Effect of Altitude on Water Availability

Altitude has an effect on water availability. This effect can be seen from several aspects such as climate, water resources and vegetation. Areas with higher altitudes have high rainfall with low evaporation which is inversely proportional to lowlands (Oyler et al., 2015). This also affects the reduction in the rate of evaporation due to lower temperatures at high altitudes. Altitude can affect the

characteristics and ability of the soil to store water. In a study by Rad et al., (2021) showed that corn plants planted in the highlands are more susceptible to water stress than in the lowlands, especially in areas with insufficient rainfall. In addition, low water availability can affect the yield of the plant. In its growth, corn plants on land that does not have irrigation require optimal rainfall of around 85-200 mm/month (Paeru and Dewi, 2017).

III. RESEARCH METHODOLOGY

This research was conducted in December - January 2025 at the East Java Climatology Station. The research was conducted by examining the corn production areas in East Java Province located in Tuban Regency and Malang Regency. The map of Tuban Regency and Malang Regency is presented in Figure 3. Tuban Regency is one of the regencies located in East Java Province. Tuban Regency is located at 111030 '- 112035' East Longitude and 6040' - 7018' South Latitude which is presented in Figure 3a. Tuban Regency is directly adjacent to the Java Sea to the North, Lamongan Regency to the East, Bojonegoro Regency to the South and Central Java Province to the West. Tuban Regency is at an altitude of 5-182 meters above sea level (masl). In 2023, the annual rainfall of Tuban Regency was 907.8 mm with 104 rainy days and the average temperature of Tuban Regency ranged from 27.1°C - 29.7°C (Central Statistics Agency of Tuban Regency, 2024).

Malang Regency is located in the South Central part of East Java Province. Malang Regency is located between 112.060 - 112.070 East Longitude and 7.060-8.020 South Latitude which is presented in Figure 3b. Malang Regency borders Pasuruan and Probolinggo Regencies to the North-East, Lumajang Regency to the East, the Indonesian Ocean to the South, Blitar Regency to the West and Kediri and Mojokerto Regencies to the North West. Malang Regency is located at an altitude of 250-500 meters above sea level (masl) in the central region, 0-650 meters above sea level (masl) in the southern region, 500-3,600 meters above sea level (masl) in the eastern region from north to south and 500-3,300 meters above sea level (masl) in the western region. In 2023, the annual rainfall of Malang Regency is around 1686 mm with 151 rainy days and an average temperature ranging from 22.4°C - 25.76°C (Central Statistics Agency of Malang Regency, 2024).

The tools used in the study include Spreadsheet and R Statistic applications. The materials used in this study are monthly rainfall projection data, minimum temperature, maximum temperature and average temperature. In addition, there is also data on the longitude and latitude of the study area, root depth, depletion fraction, pan evaporation, crop coefficient and correction factor. The climate projection scenario data used is the Representative Concentration Pathways (RCP) 4.5 and 8.5 REG CM 4 and CSIRO MK 3.6 models. This study uses a descriptive analysis method which is a statistical method used to analyze data by describing or describing the data collected to provide an overview of the problems that occur. The descriptive method is a method used to analyze by describing problems that have occurred or that have occurred. This method is described in the form of tables, graphs, diagrams, or measures of data centralization and distribution. In preparing the research, it is also necessary to conduct a literature study to analyze the problems that occur and also previous research on the problem. After the problem of interest to the researcher is determined, information from previous studies is collected. Furthermore, data collection in the form of climate data from 1991-2020 and projection data for 2021-2099. In addition, there is also other data used to calculate irrigation needs and potential harvest yields.

The technique for determining the location of the study used the purposive sampling method. According to Sugiono (2015), purposive sampling is a sampling technique based on certain considerations according to the required criteria. The criteria determined are based on the area of corn production centers and represent different altitudes in the regions in East Java Province. The areas selected in this study were Tuban Regency which represents the largest production center in East Java Province and Tuban Regency which represents the lowlands and Malang Regency which represents the Middle Plains. The scope of this area is designed to represent the diversity of climate conditions such as rainfall and temperature in different regions. In addition, in Tuban Regency and Malang Regency, 1 sub-district with the largest production in each region was taken to determine the land point that would be used as the coordinate point in determining the data. The coordinates used in Tuban Regency are 8.316137 ° and 112.398505 °. while the coordinates used in Tuban Regency are 6.890742 ° and 111.888973 °. The data used and collected in this study are historical climate data, projection data and data for calculating the water requirements of corn in Tuban Regency and Malang Regency. The data collected are secondary data consisting of: Historical rainfall and temperature data from 1991-2020 obtained from the Meteorology, Climatology and Geophysics Agency. Climate projection data from the East Java Climatology Station from 2021 to 2080. The climate model data used are REG CM 4 and CSIRO MK 3.6 in the RCP 4.5 and RCP 8.5 scenarios. Field Capacity (KP) data with a value of 462 mm and Permanent Wilting Point (TLP) with a value of 229 mm from the Harmonized World Soil Database (HWSD) website and research by Prasojo et al., (2022). Longitude

and latitude data for the study area to extract projection data. Root depth, depletion fraction, and crop coefficient data obtained from FAO 56. Pan evaporation data obtained from the East Java Climatology Station.

The collected data will be processed by making projections from the models obtained for each parameter based on projection data from RCP 4.5 and RCP 8.5. The climate projection model used is described in Table 1. The data processing process is carried out using the R-statistic application with a script quoted from Kurniawan's research, (2024) with the following steps presented in Figure 4. Extraction of projection data for rainfall, maximum temperature, minimum temperature and average temperature. Calculation of evapotranspiration using the Hargreaves-Samani equation method in FAO 56. Validation test on projection data and data with the most accurate validation is selected. Calculation of groundwater availability (KAT) using monthly rainfall, plant evapotranspiration (Etc) and field capacity (KL). Calculation of available groundwater (ATS) using KAT, Field Capacity and Permanent Wilting Point. Calculation of target KAT using KAT and depletion fraction. Calculation of irrigation water requirements and calculation of potential harvest yields. The validation test used in this study is the Mean Absolute Error (MAE). MAE is a method of measuring the level of accuracy in a forecasting model. The MAE value is the average of the absolute error in the forecast results with the real value. In the MAE equation, it can be seen that the calculation of the average error uses the same weight for all data (i = 1). MAE is more intuitive in providing an average error to evaluate the forecasting model from all data. The results of the validation test were carried out on the RCP 4.5 and RCP 8.5 scenarios in the period 1991-2020. The results of the validation test will later be used for climate projection data for the period 2021-2099.

The data analysis used in this study is the calculation of irrigation water requirements based on groundwater availability. The calculation stages carried out include: Field Capacity and Permanent Wilting Point, using soil data from HWSD and certain formulas; Evapotranspiration with the Hargreaves-Samani equation based on temperature data; Plant coefficient based on FAO 56 with Kc values adjusted for each phase; Groundwater Availability (KAT) and target KAT using the Thornwaite-Mather method; and Available Groundwater (ATS) in percent and irrigation water requirements based on the difference in value between the target and actual KAT. All of these stages are used to support the calculation of potential harvest yields based on water conditions during the plant growth period. The corn plant coefficient curve at several growth phases including the early period, development period, middle period and final period is displayed in graphical form and is a reference in calculating water requirements and potential harvest yields. This growth period is directly related to different water requirements, thus providing a detailed picture for decision making in irrigation and harvest projections. This research as a whole aims to provide an overview of future climate projections and their impact on corn plant growth through a measurable and systematic scientific and computational approach.

IV. RESULT & DISCUSSION

The results of the validation test were carried out on the RCP 4.5 and RCP 8.5 scenarios in the period 1991-2020. The results of the validation test will later be used for climate projection data for the period 2021-2099. The validation test was carried out using the Mean Absolute Error (MAE) method with the results presented in Table 5 and Table 7. Validation was carried out on rainfall in Tuban Regency and Malang Regency as well as on maximum temperature, minimum temperature and average temperature. Validation was carried out on two models, namely the CSIRO MK 3.6 model and the REG CM 4 model.

Based on the validation results, the smallest MAE value is used to determine which data is used in the projection. For rainfall data for Tuban Regency and Malang Regency, the data used is the projection data from the CSIRO MK 3.6 model. For maximum temperature, minimum temperature, and average temperature data for Tuban Regency and Malang Regency, data from the REG CM 4 model is used because it has the smallest MAE value compared to other models.

Historical rainfall data for Tuban Regency and Malang Regency are presented in Figure 6 and Figure 7. The figures show the historical trend of rainfall from 1991 to 2020. Furthermore, rainfall projections based on the RCP 4.5 and RCP 8.5 scenarios are shown in Figure 8 to Figure 15 which show projections for the periods 2021-2050 and 2051-2080 for each district.

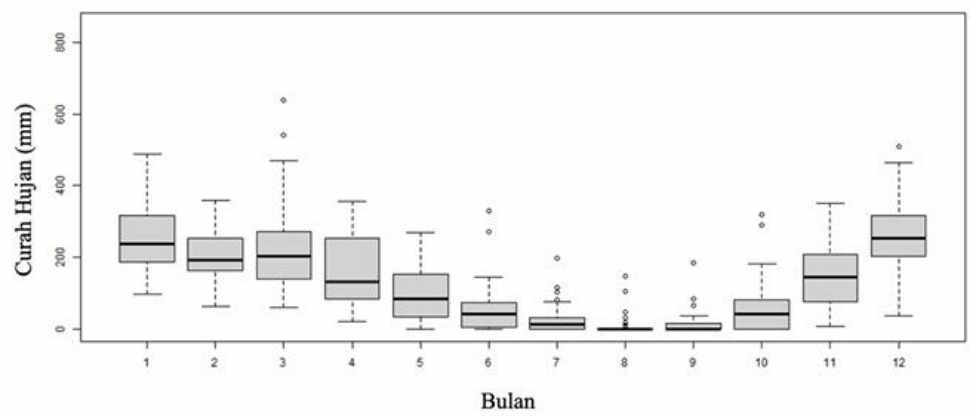

Fig1 Historical Rainfall Data for Tuban Regency

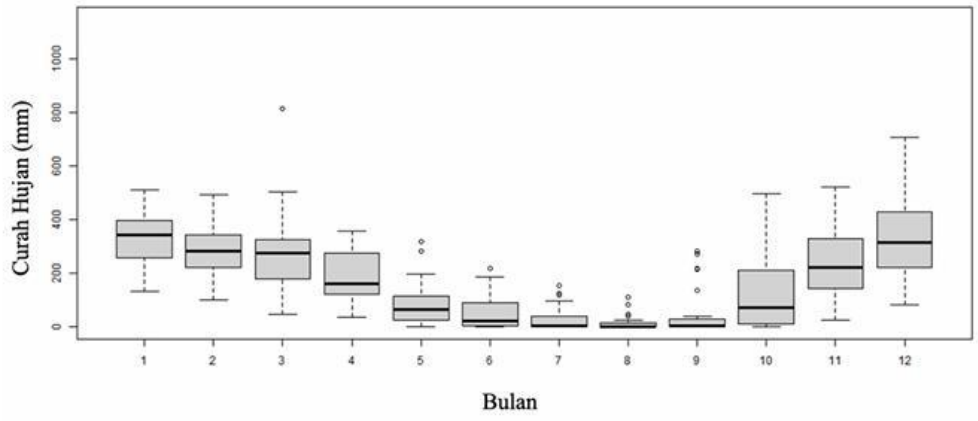

Fig.2 Historical Rainfall Data in Malang Regency

The results of rainfall projections based on RCP 4.5 and 8.5 scenarios in Tuban Regency and Malang Regency show an increase and fluctuation in rainfall. Figures 8 to 11 show rainfall in Tuban Regency and Malang Regency based on RCP 4.5. Figures 12 to 15 show rainfall based on RCP 8.5. RCP 8.5 shows a higher increase in rainfall.

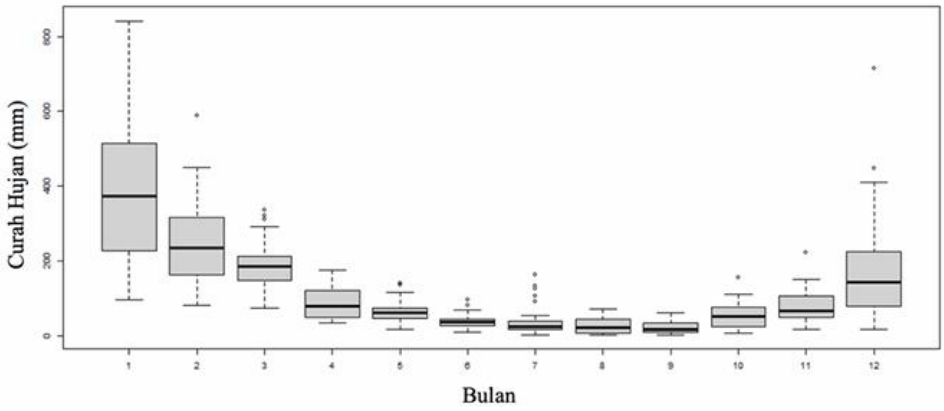

Fig.3 Results of RCP 4.5 Rainfall Projection for 2021-2050 in Tuban Regency

Based on the results of the RCP 4.5 rainfall projection in Tuban Regency in 2021-2050, there has been an increase with a stable trend. The highest rainfall occurs in January and February. The lowest rainfall occurs in August and September. January has an average rainfall of 303 mm and February has a rainfall of 291 mm. In August,

rainfall is only 19 mm and in September it is 25 mm. This increase in rainfall is influenced by climate projections which show a gradual increase in rainfall intensity. However, there are dry months that still have low rainfall so good water management planning is needed.

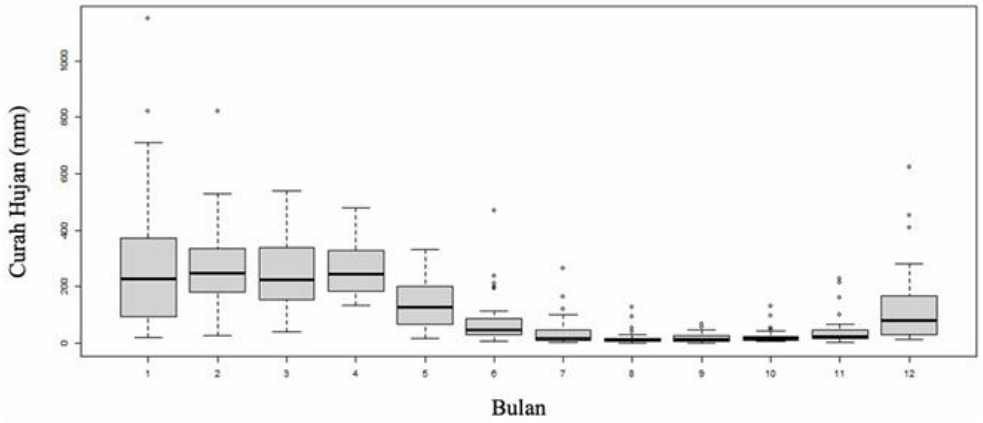

Fig.4 Results of Rainfall Projection RCP 8.5 2021-2050 in Malang Regency

Based on the results of the RCP 8.5 scenario rainfall projection in Malang Regency in 2021-2050, it shows a significant increase in rainfall compared to the historical period. The highest rainfall occurs in January with an average of 403 mm and February with 395 mm. The lowest rainfall occurs in August with 31 mm and September with 45 mm. This increase in rainfall shows a higher wet trend compared to the RCP 4.5 scenario. Although rainfall increases, the dry season still occurs and the dry months still show low rainfall. Therefore, adaptation strategies are still needed to deal with the drought period.

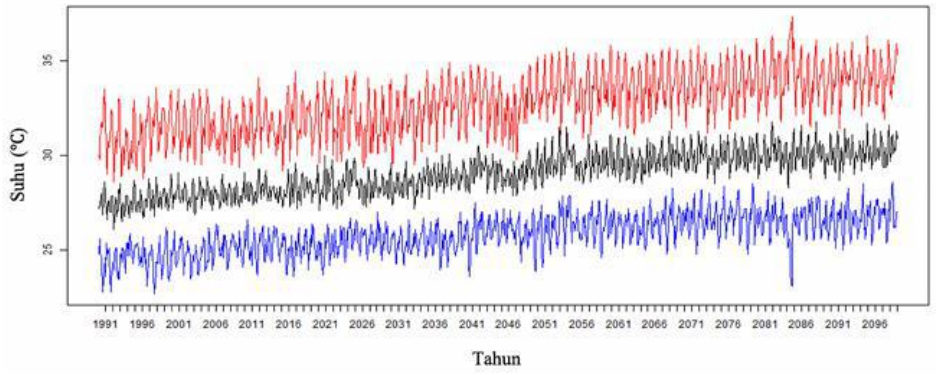

Fig.5 Observation Data and Projection Results of RCP 4.5 Temperature for 2021-2080 in Tuban Regency

Based on the results of temperature projections in the RCP 4.5 scenario for 2021-2099 in Tuban Regency, there has been an increase from year to year. The average maximum temperature is 33.1°C, the minimum temperature is 24.1°C and the average temperature is 28.3°C. This increase in temperature can have an impact on the increasing water needs of corn plants. High temperatures will cause high evaporation and plant evapotranspiration will also increase. This causes the need for irrigation of corn plants to be higher than before.

Evapotranspiration is calculated using the Hargreaves-Samani method. The results of the evapotranspiration calculation are used as the basis for calculating irrigation needs. High evapotranspiration values will affect plant water needs, especially in dry months. Evapotranspiration is also affected by maximum and minimum temperatures which show fluctuations in the projection scenario.

Irrigation water needs are calculated using the same and different assumptions of Kc (crop coefficient) values. The results of the calculation of irrigation needs for Tuban Regency with the same Kc assumption in the RCP 4.5 scenario are shown in Figure 6. Irrigation needs tend to increase in August and September.

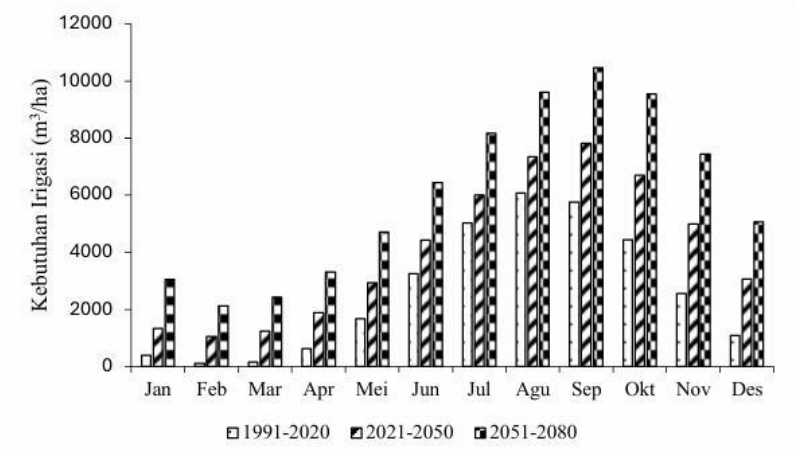

Fig.6 Irrigation Needs Assumption of Same Kc in Tuban Regency RCP 4.5

Based on the results of temperature projections in the RCP 4.5 scenario for 2021-2099 in Tuban Regency, there has been an increase from year to year. The average maximum temperature is 33.1°C, the minimum temperature is 24.1°C and the average temperature is 28.3°C. This increase in temperature can have an impact on the increasing water needs of corn plants. High temperatures will cause high evaporation and plant evapotranspiration will also increase. This causes the need for irrigation of corn plants to be higher than before.

In the RCP 8.5 scenario, the irrigation needs of Tuban Regency increased higher compared to RCP 4.5. This is shown by the illustration showing the irrigation needs with the same and different Kc assumptions. The difference in irrigation water needs is influenced by the projection of increasing temperatures and uneven rainfall. Another illustration shows the irrigation needs of Malang Regency with the same and different Kc assumptions in the RCP 4.5 scenario, as well as in the RCP 8.5 scenario. Malang Regency tends to need lower irrigation water compared to Tuban Regency. The potential yield is calculated based on the availability of groundwater and the water needs of plants during the growing period. Groundwater depletion can have an impact on the yield. Ilustrate show the potential yield of Tuban Regency assuming the same and different Kc values in RCP 4.5.

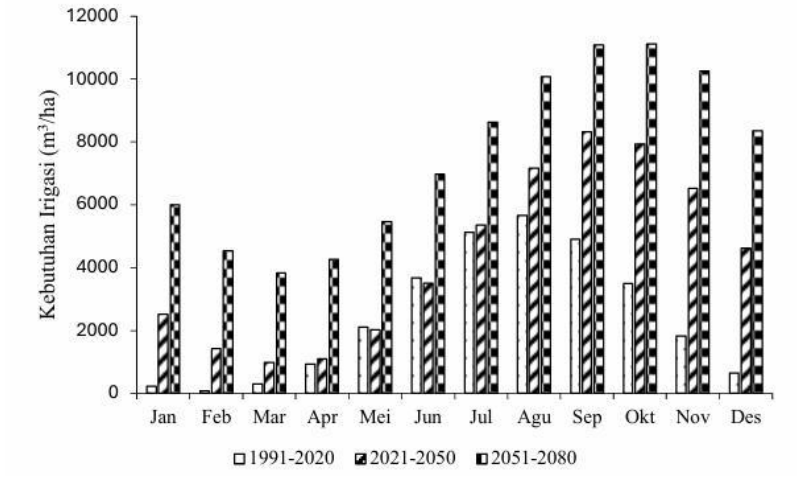

Fig.7 Irrigation Needs Assumption of Same Kc in Malang Regency RCP 8.5

Based on Figure 7, the irrigation water requirement Kc is the same in Malang Regency, RCP 8.5 scenario. The highest irrigation requirement occurs in August at 112 mm and September at 95 mm. Irrigation requirements in November to March show a figure of 0 because rainfall is high enough to meet plant water requirements. Irrigation

requirements increase in the dry season, especially in dry months with low rainfall. Malang Regency has lower water requirements compared to Tuban Regency due to higher rainfall and lower temperatures.

Figure 8 shows the potential harvest of Tuban Regency assuming the same and different Kc values in the RCP 8.5 scenario. The potential harvest decreased especially in months with low water availability. Tuban Regency showed a more drastic decrease in harvest. The potential harvest of Malang Regency in the RCP 4.5 scenario is shown in Figure 32 and Figure 33. Meanwhile, for RCP 8.5 it is shown in Figure 34 and Figure 35. Malang Regency experienced a decrease in harvest that was not too significant because rainfall was higher and temperatures did not increase as sharply as Tuban Regency.

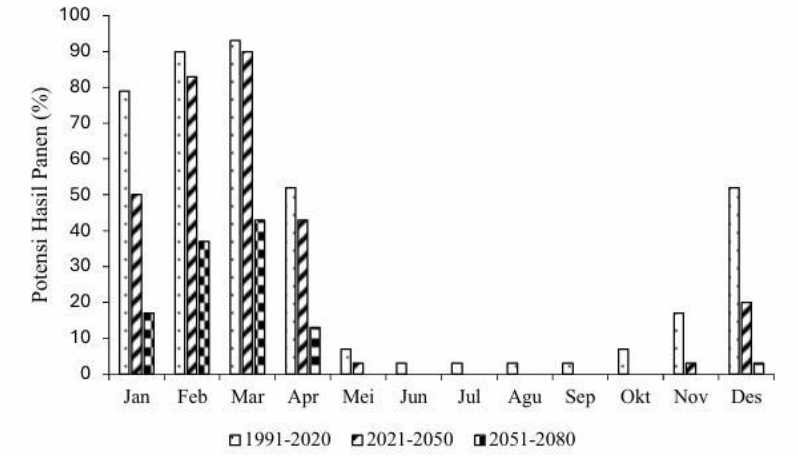

Fig.8 Potential Harvest Yield Assuming Same Kc Value in Tuban Regency RCP 8.5

Based on Figure 8, the potential yield of Kc is the same in Tuban Regency, RCP 8.5 scenario. The highest potential yield occurs in January at 6.81 tons/ha and February at 6.65 tons/ha. The lowest potential yield occurs in September at 4.37 tons/ha. The decrease in potential yield is caused by the high need for irrigation water which is not balanced by the availability of groundwater, so that the plants experience a water deficit. Water deficit in corn plants will disrupt growth, especially in the generative phase and result in a decrease in yield.

Based on the projection of rainfall and temperature in the two study areas, namely Tuban and Malang Regencies, it shows fluctuations from 1991 to 2080. Historical data shows the same seasonal rainfall pattern between the two regions seen at the peak of the rainy season which is in December to March and the dry season in May - September. In the period 2021-2050 using RCP 4.5, rainfall is projected with a relatively high rainfall intensity in the rainy season, namely in January - March reaching 400 mm and the dry season in June-October. While in scenario 8.5, rainfall shows higher variations compared to RCP 4.5 in the rainy season and a fairly high decrease in the dry season in July - October. In the period 2051-2080 which is projected using RCP 4.5, it shows a fairly high rainfall intensity with a rainy season in January to March with a lower dry season compared to the previous year period, namely in July to October. Meanwhile, in projection 8.5, rainfall increases quite sharply and the dry season shows almost zero rainfall. Tuban and Malang Regencies have the same rainfall distribution pattern, but Malang Regency has a higher rainfall intensity (Figure 14).

The rainfall distribution pattern in Tuban and Malang Regencies has a difference in rainfall intensity which is slightly higher in Malang Regency. This is because Malang Regency has a higher elevation compared to Tuban Regency which is at a lower altitude. Elevation or height of a place has a significant influence on the climate factors of rainfall and temperature, where rainfall will increase on higher surfaces (Lesik et al., 2020). In addition, altitude can also affect air temperature which causes a decrease in temperature. Malang Regency has a lower temperature with the highest temperature at 35°C while in Tuban Regency the highest projected temperature reaches 38°C in the RCP 4.5 scenario. In the RCP 8.5 scenario, the highest temperature in both regions ranges from 35-40°C. This is in accordance with the opinion of Zhang et al. (2019) that temperature projections will result in a greater increase in maximum and minimum temperatures using the RCP 8.5 scenario compared to RCP 4.5.

Based on the projection results using RCP 4.5 and 8.5, it can be seen that the RCP 8.5 scenario has a higher value when compared to the RCP 4.5 scenario. According to Khoirunisa (2022), the prediction results for 2021-2080 show that the 4.5 scenario as a pessimistic scenario with radiative forcing (RF) of 4.5 w/m² in both aspects is more stable, while the 8.5 scenario with RF around 8.5 w/m² experiences an unstable decrease and increase. This Radiative Forcing is a parameter for determining climate change. The RF value is directly proportional to the energy entering the earth. This is inversely proportional to the change in the level of CO_2 concentration, which is getting smaller, meaning that more energy will enter (Prasetiawan, 2015). Increases in maximum and minimum temperatures exceeding 3.4 and 3.8°C can result in soil degradation and water shortages, which can significantly reduce crop yields.

According to IPCC calculations, the global average temperature will increase by around 2°C by 2100 and 4.2°C by 2400 (Malhi et al., 2021). Corn plants can generally grow optimally at temperatures of 28 - 32°C. This increase in temperature and decreased water availability can reduce the duration of the growing season in corn plants by up to 16 days (Ahmad et al., 2020). This can disrupt the reproductive period in corn and affect the yield of corn seeds. According to Shao et al. (2021), corn plants exposed to temperatures of 35°C and above, especially during the reproductive period, can affect the success of reproduction and seed formation. High temperatures can damage the embryo so that germination will be delayed. High temperatures can also cause faster plant phenological phase transitions, increased leaf transpiration rates and reduced photosynthesis rates (Chen et al., 2020). As a result, corn plant productivity will decrease due to increasing temperatures, while rainfall becomes uneven.

V. CONCLUSION

Based on the projection of RCP 4.5 and 8.5 scenarios, decreasing rainfall and increasing temperature in Tuban and Malang districts are correlated with increasing irrigation water needs, especially in August and September, while potential yields are expected to decrease with Tuban district being more vulnerable due to lower rainfall. For further research, it is recommended to use direct calculation data through field testing to improve accuracy, as well as to explore adaptation strategies and impacts on farmers in dealing with decreasing corn yields..

ACKNOWLEDGEMENTS

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

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International Journal of Environment, Agriculture and Biotechnology
Vol-10, Issue-3; May-Jun, 2025
Peer-Reviewed International Journal
Journal Home Page Available: https://ijeab.com/
Journal DOI: 10.22161/ijeab

Response of Red Fountain Grass (*Pennisetum setaceum* var. rubrum) to the Frequency of Ecoenzyme Application and Dosage of Chicken Manure Fertilizer

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Received: 13 May 2025; Received in revised form: 09 Jun 2025; Accepted: 16 Jun 2025; Available online: 21 Jun 2025

Abstract— *Red fountain grass is an ornamental plant commonly used in residential areas and city parks. As the number of residential areas and city parks increases, so does the demand for this plant. However, the increase in market demand is not in line with the availability of the plant. This imbalance is caused by various factors, one of which is fertilization. Continuous use of inorganic fertilizers will cause a decline in soil quality. Reducing the use of inorganic fertilizers can be balanced by using organic fertilizers combined with ecoenzyme application to ensure adequate nutrient supply. The experimental design used was a Randomized Block Design arranged in a factorial layout. The first factor was ecoenzyme application frequency (no ecoenzyme, once a week, and once every two weeks). The second factor was the dose of chicken manure fertilizer (0 tons ha^{-1}, 10 tons ha^{-1}, and 20 tons ha^{-1}). The results showed that the frequency of ecoenzyme application interacted with the dose of chicken manure fertilizer on the variables of plant height, number of leaves, leaf area, number of shoots, root volume, fresh plant weight, dry plant weight, and number of flowers. The optimal dosage of chicken manure fertilizer for promoting the growth and flowering of red fountain grass is 8.56 tons ha-1 and 9.28 tons ha-1 when applied with ecoenzyme. The appropriate application frequency of ecoenzyme is once every two weeks to enhance the growth and flowering of red fountain grass.*

Keywords— ***Red Fountain Grass, landscape, Chicken Manure, Ecoenzyme***

I. INTRODUCTION

Red fountain grass (*Pennisetum setaceum* var. rubrum) is an ornamental grass plant whose aesthetic value stems from the uniqueness of its flower shape and leaf color, making it popular and widely sought after as a landscape plant in residential areas and city parks for use as a border, guide, and roadside decoration. The increasing growth in population and high rates of urbanization have led to an increase in the development of residential areas and urban parks. According to data from the Central Statistics Agency (BPS, 2021), Indonesia's population increased to 270.2 million in 2020, while the percentage of the population living in urban areas is estimated to rise to 66.60% by 2035. This trend indicates that the demand for residential areas and urban parks as green open spaces in Indonesia will continue to grow. The increase in the development of residential areas and urban parks has led to an increase in the demand for red fountain grass as a landscaping plant. However, there is a problem where the increase in market demand for red fountain grass is not in line with the availability of production of this plant. This problem is caused by various factors, including cultivation techniques that are still not appropriate, especially in terms of fertilization.

Fertilization of red fountain grass plants generally uses inorganic fertilizers. However, the continuous use of inorganic fertilizers will certainly result in a decline in soil quality. The use of inorganic fertilizers can increase soil acidity, and if used continuously, this can lead to increased soil acidity, which can disrupt the balance of soil

microorganism activity and reduce the availability of nutrients for plants (Liu *et al*., 2023). Given the adverse effects of inorganic fertilizer use, efforts should be made to reduce its use by combining organic fertilizer with ecoenzyme application to ensure adequate nutrient supply for plants.

Organic fertilizers have been proven to be beneficial for improving soil quality in a sustainable manner. One type of organic fertilizer that is commonly used is manure. Manure fertilizer is derived from the waste of livestock and poultry, such as cows, buffaloes, goats, and chickens. Among various sources of manure fertilizer, chicken manure is known to contain higher levels of nitrogen (N), phosphorus (P), and potassium (K) compared to other types of manure fertilizer (Fitrah, 2022). Additionally, the organic matter content in chicken manure has a higher percentage of organic matter compared to some other types of manure. Furthermore, the C/N ratio of chicken manure falls into the low category, indicating that chicken manure decomposes more quickly (Romadhon *et al*., 2024). Based on research conducted by Simon (2023), the application of chicken manure has a significant effect on the growth and yield of corn plants. The variables observed that have a significant effect are plant height, number of leaves, and fresh weight of corn without cobs.

The performance of manure in improving soil quality can be optimized through the use of ecoenzymes. Ecoenzymes are solutions produced through the fermentation of complex organic compounds derived from organic waste, which have high utility value in various fields such as agriculture, health, livestock, and household applications (Hidayat *et al*., 2022). In the agricultural sector, ecoenzymes are used as biocatalysts and botanical pesticides (Hasanah, 2021). The application of ecoenzyme is closely related to microbial activity. Ecoenzyme contains various microorganisms such as bacteria and fungi that play a role in the ecoenzyme fermentation process, particularly in producing various enzymes such as protease, amylase, lipase, and cellulase (Gu *et al*., 2021). These enzymes have roles, one of which is related to the decomposition of organic matter by soil microorganisms. The organic matter present in the growing medium serves as a nutrient source for soil microorganisms, and this process is catalyzed by the enzymes present in ecoenzymes (Kaneko *et al*., 2002).

Enzyme activity in ecoenzymes can decrease over time, especially if the decomposition process is ongoing. Therefore, in order for enzyme performance to remain stable under continuous conditions, it is necessary to apply ecoenzymes periodically. Based on research by Nisa and Sitawati (2024), applying ecoenzyme once a week to potted chrysanthemum plants can produce optimal growth and flowering results. However, applying ecoenzyme once a week can trigger a possible imbalance in the nutrients released (Paillat *et al*., 2020). Therefore, to prevent such risks, ecoenzyme application was adjusted to an appropriate frequency, specifically every two weeks in this study. Differences in application frequency result in varying doses received by the plants. The more frequent the application, the higher the ecoenzyme dose received by the plants. By applying chicken manure fertilizer at various doses and ecoenzyme at the appropriate frequency, it is hoped that this will enhance the growth and flowering of red fountain grass. This study aims to provide recommendations for the optimal dose of chicken manure fertilizer and the appropriate frequency of ecoenzyme application to improve growth and flowering in red fountain grass.

II. MATERIALS AND METHODS

2.1 Research Site

The experiment was conducted from October 2024 to January 2025 at the Jatimulyo Experimental Garden located in Jatimulyo Village, Lowokwaru District, Malang City, East Java. The research site is situated at an elevation of 440 meters above sea level, with an average air temperature ranging from 22.7–25.1°C and relative humidity ranging from 79%–86% (Pemerintah Kota Malang, 2022).

2.2 Experimental Design and Treatments

The experimental design used in this study was a factorial experiment consisting of two factors using a Randomized Block Design (RBD). The first factor is the frequency of ecoenzyme application (no ecoenzyme, ecoenzyme once a week, ecoenzyme once every two weeks), and the second factor is the dose of chicken manure fertilizer (0 tons ha^{-1}, 10 tons ha^{-1}, and 20 tons ha^{-1}). The resulting treatment combinations were 9 combinations, and each treatment combination was replicated 3 times, resulting in a total of 27 treatment combinations. Each treatment unit contained 10 plants, so the total number of plants required in this experiment was 270 plants. The observations conducted included growth measurements such as plant height, number of leaves, leaf area, number of tillers, root volume, fresh weight, and dry weight. Flowering observations included flowering time, flower stalk length, flower spike length, and number of flowers.

2.3 Data Collection and Analysis

Data analysis was performed using ANOVA at the 5% level. If the test results show a real efferc then at the Least Significant Difference test is continued at the 5%.

III. RESULT AND DISCUSSION

The application of ecoenzyme frequency and chicken manure fertilizer had an effect on the growth and flowering of red fountain grass plants. Based on the analysis of variance, it was found that there was an interaction between the application of ecoenzyme frequency and chicken manure fertilizer on plant length, number of leaves, leaf area, number of tillers, root volume, fresh plant weight, dry plant weight, and number of flowers.

3.1 Plant Length (cm)

The analysis of variance conducted on plant length showed a significant interaction between the application frequency of ecoenzyme and chicken manure. The interaction between plant length due to the application frequency of ecoenzyme and chicken manure can be seen in Table 1.

Application of ecoenzyme once a week with a chicken manure fertilizer dose of 10 tons ha^{-1} could increase plant length by up to 35.54% compared to the control treatment, which was plants without ecoenzyme application and without chicken manure fertilizer. Chicken manure fertilizer at a dose of 10 tons ha^{-1} can provide balanced macro and micro nutrients for vegetative plant growth. According to Rengga *et al*. (2022), chicken manure fertilizer contains nitrogen, phosphorus, potassium, magnesium, and manganese required by plants. During the vegetative phase, plants require nitrogen nutrients to stimulate growth, particularly of stems, branches, and leaves (Pramitasari *et al*., 2016).

The nitrogen content in chicken manure cannot be directly absorbed by plants because it is still in the form of organic nitrogen in the form of protein (Makenova *et al*., 2024). Nitrogen can be absorbed by plants if it is in the form of inorganic nitrogen in the form of nitrate. Ecoenzyme contains protease enzymes that play a crucial role in accelerating nitrogen mineralization. Protease enzymes break down proteins in manure to produce amino acids and urea (Rukmi *et al*., 2019). Then, amino acids and urea are converted into nitrate through the nitrification process, which is ready to be absorbed by plants for vegetative growth.

3.2 Number of Leaves (leaves $clump^{-1}$) and Leaf Area (cm^2 $clump^{-1}$)

Analysis of variance conducted on the number of leaves and leaf area showed a significant interaction between the application frequency of ecoenzyme and chicken manure. The interaction between the number of leaves and leaf area due to the application frequency of ecoenzyme and chicken manure fertilizer can be seen in Table 2 and Table 3.

Application of ecoenzyme once a week with a chicken manure fertilizer dose of 10 tons ha^{-1} can increase the number of leaves by up to 42.59% and leaf area by up to 92.56% compared to the control treatment. The nitrogen content in chicken manure is one of the essential macronutrients that plays a role in leaf growth. Nitrogen is involved in the photosynthesis process as a component of chlorophyll (Pérez-Molina *et al*., 2020). An increase in chlorophyll content enhances photosynthesis rates, thereby increasing photosynthates for vegetative plant growth (Fathi, 2022). Meanwhile, ecoenzymes accelerate nitrogen mineralization, enabling its absorption by plants through the assistance of protease enzymes and microorganisms (Fadlilla *et al.,* 2023). If nitrogen mineralization can occur optimally and quickly, it can cause nitrate availability to increase, making nutrients easier to absorb and enhancing the formation of vegetative organs such as plant leaves.

In this experiment, the number of leaves had a positive correlation with leaf area. The positive correlation created between these two variables is that the greater the number of leaves, the greater the total leaf area. The leaf area variable is related to the capacity to absorb sunlight for photosynthesis (Mathur *et al*., 2018). The larger the leaf area, the more light is absorbed, resulting in higher photosynthetic activity (Setyanti *et al*., 2013).

3.3 Number of Tillers (tiller $clump^{-1}$)

Analysis of variance conducted on the number of tillers showed a significant interaction between the application frequency of ecoenzyme and chicken manure. The interaction between the number of tillers due to the application frequency of ecoenzyme and chicken manure fertilizer can be seen in Table 4.

The number of tillers is a variable related to the plant's ability to reproduce. Based on the results of the analysis of variance, it is known that the application of ecoenzyme once a week with a dose of chicken manure fertilizer of 10 tons ha^{-1} can increase the number of offspring by up to 49.44% compared to the control treatment. The interaction between the application of ecoenzyme once a week with a chicken manure dose of 10 tons ha^{-1} can increase the number of seedlings due to sufficient nutrients and the role of ecoenzyme in enhancing the decomposition process of organic matter.

Table 1. Effect of Ecoenzyme Frequency and Chicken Manure Fertilizer Dosage on the Plant Length of Red Fountain Grass Plants

Ecoenzyme Application Frequency	Plant Length (cm)		
	Chicken Manure Fertilizer Dosage (ton ha^{-1})		
	0	**10**	**20**
Without Ecoenzyme	51,57 a	55,53 ab	65,47 ab
Once a week	62,47 ab	69,90 b	56,33 ab
Once of two week	64,13 ab	67,33 ab	54,53 ab
HSD 5%: 17,93			

Note: Mean values with the same notation in columns and rows have no significant difference based on the 5% HSD follow-up test.

Table 2. Effect of Ecoenzyme Frequency and Chicken Manure Fertilizer Dosage on the Number of Leaves of Red Fountain Grass Plants

Ecoenzyme Application Frequency	Number of Leaves (leaves clump^{-1})		
	Chicken Manure Fertilizer Dosage (ton ha^{-1})		
	0	**10**	**20**
Without Ecoenzyme	114,77 a	126,67 a	148,23 ab
Once a week	136,47 ab	176,43 b	129,53 a
Once of two week	140,90 ab	159,23 ab	122,90 a
HSD 5%: 46,37			

Note: Mean values with the same notation in columns and rows have no significant difference based on the 5% HSD follow-up test.

Table 3. Effect of Ecoenzyme Frequency and Chicken Manure Fertilizer Dosage on the Leaf Area of Red Fountain Grass Plants

Ecoenzyme Application Frequency	Leaf Area (cm^2 clump^{-1})		
	Chicken Manure Fertilizer Dosage (ton ha^{-1})		
	0	10	20
Without Ecoenzyme	1926,41 a	2418,10 ab	2944,08 bcd
Once a week	2669,07 abc	3709,50 d	2589,39 ab
Once of two week	2791,93 abcd	3613,11 cd	2319,59 ab
HSD 5%: 988,29			

Note: Mean values with the same notation in columns and rows have no significant difference based on the 5% HSD follow-up test.

Table 4. Effect of Ecoenzyme Frequency and Chicken Manure Fertilizer Dosage on the Number of Tillers of Red Fountain Grass Plants

Ecoenzyme Application Frequency	Number of Tillers (tiller clump^{-1})		
	Chicken Manure Fertilizer Dosage (ton ha^{-1})		
	0	**10**	**20**
Without Ecoenzyme	**22,53 a**	**26,57 ab**	**31,33 ab**
Once a week	**28,67 ab**	**33,67 b**	**27,00 ab**
Once of two week	**29,77 ab**	**32,23 ab**	**26,10 ab**
HSD 5%: 9,88			

Note: Mean values with the same notation in columns and rows have no significant difference based on the 5% HSD follow-up test.

Chicken manure fertilizer contains nitrogen and phosphorus nutrients that are related to plant growth. Nitrogen is needed in vegetative growth for the formation of leaves, roots, stems, and shoots. Nitrogen plays a role in the formation of chlorophyll for leaf photosynthesis. According to Zhang *et al*. (2022), the greater the number of leaves, the greater the effect on the photosynthates produced by the plant. These photosynthates are processed to form plant organs during the vegetative phase. The vegetative phase of a plant begins with the formation of roots and leaves, followed by the formation of shoots (Suaria *et al*., 2017). Meanwhile, phosphorus can stimulate root development and promote tiller growth. This is because phosphorus is a core component of cells that plays a crucial role in cell division within meristematic tissue. Healthy root growth enhances nutrient absorption (Awliya *et al.,* 2022). In plants of the Poaceae family, new tillers emerge from axillary buds at the base of the stem (George and Rice., 2020). Phosphorus accelerates meristem activity in the axillary bud area, resulting in more buds developing into tillers (Zhua and Wagner., 2020). Phosphorus in manure fertilizer is still in the form of organic phosphorus, which is not yet available to plants. Organic phosphorus must be broken down by microorganisms into phosphate to become available to plants (García-Berumen *et al*., 2025). Ecoenzymes can accelerate the breakdown process with the help of organic acids that bind aluminum and iron ions (Drábek *et al*., 2015).

3.4 Root Volume (cm^3)

Analysis of variance conducted on the root volume showed a significant interaction between the application frequency of ecoenzyme and chicken manure. The interaction between the root volume due to the application frequency of ecoenzyme and chicken manure fertilizer can be seen in Table 5.

Roots are part of the vegetative organs that absorb available nutrients for plants. Based on the results of the analysis of variance, it is known that the application of ecoenzyme once a week with a dose of chicken manure fertilizer of 10 tons ha^{-1} can increase root volume by up to 100.01% compared to the control treatment. The interaction between the application of ecoenzyme once a week with a dose of 10 tons ha^{-1} of chicken manure per hectare can increase root volume because chicken manure provides nutrients while ecoenzyme helps nutrient absorption and stimulates root development.

Chicken manure contains macro and micro nutrients needed for root growth. Nitrogen is an essential macro nutrient that plays a crucial role in root growth. Nitrogen contains amino acids, proteins, and enzymes necessary for DNA and RNA synthesis. Nitrogen forms amino acids such as glutamine and asparagine, which constitute structural proteins and DNA polymerase enzymes required for cell elongation in root cells (Ohayam, 2010). Additionally, nitrogen supports the growth of secondary roots. Secondary roots are branches of the primary root that function to expand the root system (Suryo and Rixa, 2016). Nitrogen influences secondary root growth through auxin hormone synthesis. Nitrogen is required to produce tryptophan, which serves as an auxin precursor. Auxin stimulates the initiation of lateral roots and the branching of secondary roots (Aprinda *et al.,* 2022). Furthermore, phosphorus plays a crucial role in the development of early roots and the formation of root hairs (Ruiz *et al.,* 2020). Thus, balanced nutrient availability, such as at a dose of 10 tons ha^{-1}, can support root cell elongation, lateral root branching, and root hair formation, thereby increasing root volume.

Ecoenzymes can influence root growth by increasing nutrient availability. Enzymes in ecoenzyme help accelerate the breakdown of nutrients in manure, such as nitrogen and phosphorus, for root development. Additionally, regular application of ecoenzyme can influence soil microbial communities and increase the production of root-stimulating phytohormones such as auxin (Timofeeva *et al.,* 2024). Organic compounds in ecoenzyme can serve as a carbon and energy source for microbes. Microbes cannot synthesize their own food and thus depend on organic compounds for their energy source (Song *et al*., 2024). Some microbial groups that are activated by ecoenzyme application produce phytohormones that stimulate root development. Microbes such as Azospirillum, Pseudomonas, and Bacillus produce auxin from the precursor tryptophan (Rahayu *et al.,* 2024). The auxin produced can trigger root cell elongation and lateral root initiation. The formation of lateral roots directly increases root volume by enhancing root surface area and root system biomass (Wang *et al.,* 2023).

3.5 Fresh Weight of Plants

Analysis of variance conducted on the fresh weight of plants showed a significant interaction between the application frequency of ecoenzyme and chicken manure. The interaction between the fresh weight of plants due to the application frequency of ecoenzyme and chicken manure fertilizer can be seen in Table 6.

Fresh weight of plants reflects the nutrient composition and plant tissue, including water. Fresh weight is influenced by the water content in plant tissue

because most of the fresh weight of plants is water (Reski *et al*., 2021). The combination of applying ecoenzyme once a week and chicken manure fertilizer at a dose of 10 tons ha-1 synergistically increases plant fresh weight. Chicken manure fertilizer, as a nutrient source, contains nitrogen that supports chlorophyll synthesis. According to Filstrup and Dowing (2017), nitrogen is a key component of chlorophyll structure. Nitrogen is required as a basic component and builder of chlorophyll in the photosynthesis process. Sufficient chlorophyll can enhance photosynthetic efficiency in converting light energy into chemical energy to produce glucose. Optimal glucose production maintains balance between source and sink organs, so the more effective glucose distribution to sink organs, the greater biomass accumulation (Osorio *et al.,* 2014). Additionally, nitrogen can influence water absorption by increasing the synthesis of aquaporin transporter proteins in root cell membranes (Sun *et al.,* 2024). Aquaporins are integral membrane proteins that form selective water channels in the plasma membrane and vacuoles of root cells (Adeoye *et al.,* 2022). Aquaporin channels facilitate the passive flow of water from the roots to other plant organs without requiring energy, based on the principle of osmosis (Kudiyarova *et al.,* 2022). The role of ecoenzymes in this treatment combination is that regular application can accelerate the decomposition of chicken manure fertilizer, thereby releasing nutrients more quickly.

Table 5. Effect of Ecoenzyme Frequency and Chicken Manure Fertilizer Dosage on the Root Volume of Red Fountain Grass Plants

Ecoenzyme Application Frequency	Root Volume (cm^3)		
	Chicken Manure Fertilizer Dosage (ton ha^{-1})		
	0	10	20
Without Ecoenzyme	63,33 a	76,63 abc	97,80 bcd
Once a week	88,37 abc	126,67 d	84,43 abc
Once of two week	90,00 abc	105,57 cd	71,67 ab
HSD 5%: 31,88			

Note: Mean values with the same notation in columns and rows have no significant difference based on the 5% HSD follow-up test.

Table 6. Effect of Ecoenzyme Frequency and Chicken Manure Fertilizer Dosage on the Fresh Weight of Plants of Red Fountain Grass Plants

Ecoenzyme Application Frequency	Fresh Weight of Plants (g $clump^{-1}$)		
	Chicken Manure Fertilizer Dosage (ton ha^{-1})		
	0	10	20
Without Ecoenzyme	**142,77 a**	**171,23 ab**	**230,27 abc**
Once a week	**207,80 abc**	**275,03 c**	**188,47 abc**
Once of two week	**221,40 abc**	**259,80 bc**	**164,03 a**
HSD 5%: 89,65			

Note: Mean values with the same notation in columns and rows have no significant difference based on the 5% HSD follow-up test.

3.6 Dry Weight of Plants

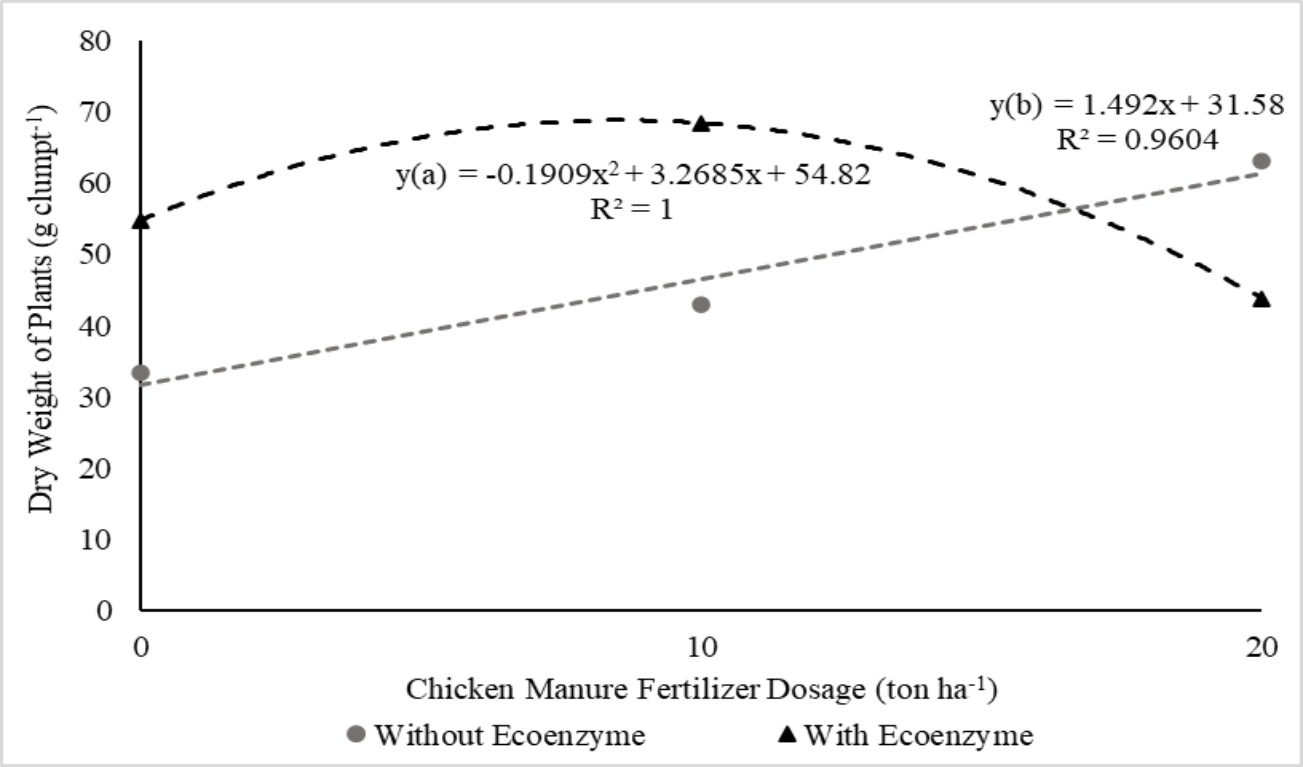
Analysis of variance conducted on the dry weight of plants showed a significant interaction between the application frequency of ecoenzyme and chicken manure. The interaction between the dry of plants due to the application frequency of ecoenzyme and chicken manure fertilizer can be seen in Table 7.

Dry weight of plants is a growth indicator related to the results of plant assimilate accumulation obtained from the total growth and development of the plant during its life. The greater the dry weight of the plant, the better the growth and development of a plant (Kartika *et al.,* 2023). The effect of chicken manure doses on plant dry weight at each ecoenzyme frequency is presented in Figure 1.

Table 7. Effect of Ecoenzyme Frequency and Chicken Manure Fertilizer Dosage on the Dry Weight of Plants of Red Fountain Grass Plants

Ecoenzyme Application Frequency	Dry Weight of Plants (g clump^{-1})		
	Chicken Manure Fertilizer Dosage (ton ha^{-1})		
	0	10	20
Without Ecoenzyme	**33,33 a**	**43,00 abc**	**63,17 bcd**
Once a week	**53,17 abcd**	**70,37 d**	**48,20 abcd**
Once of two week	**56,47 abcd**	**66,47 cd**	**39,50 ab**
HSD 5%: 24,37			

Note: Mean values with the same notation in columns and rows have no significant difference based on the 5% HSD follow-up test.



Note: (a): Application of ecoenzyme; (b): Without application of ecoenzyme

Fig 1. Effect of Manure Dose on Plant Dry Weight at Each Frequency of Ecoenzyme Application

Based on Figure 1, application of ecoenzyme, every additional 1 point of chicken manure dose causes the dry weight of the plant to increase by approximately 57.89 g clump^{-1} (y (a) = -0.1909x2 + 3.2685x + 54.82 with R2 = 1). However, when the dose of chicken manure increases to 20 tons ha^{-1}, the dry weight of the plant begins to decrease. The treatment of 10 tons ha^{-1} chicken manure produces better dry weight and then decreases when the dose of manure increases to 20 tons ha^{-1}. In the treatment of ecoenzyme application, the dry weight of the plant has the highest weight with an R2 value of 1 so that the optimum dose of chicken manure is sought using the equation y (a) = 0.1909x2 + 3.2685x + 54.82 and the results of the optimum dose of chicken manure for dry weight are 8.56 tons ha^{-1}.

The dose of chicken manure of 8.56 tons ha^{-1} is the optimum fertilizer dose for the dry weight of red fountain grass plants. At this dose, the addition of nutrients reaches the highest efficiency without excess nutrients. Through the assistance of ecoenzyme once a week, the mineralization of nutrients in chicken manure becomes faster so that nutrients are more quickly available to

plants. At a dose of 20 tons ha^{-1} of manure, the dry weight of the plant is lower. This can happen because the higher the dose of chicken manure, the higher the nitrogen content. At excessive doses, ammonia accumulation can poison the roots and interfere with the absorption of water and nutrients (Pan *et al*., 2016). In addition, excess nitrogen can also inhibit the absorption of potassium and phosphorus. The inhibition of absorption of these two elements is due to competition for ion absorption. Ammonium competes directly with K^+ because both of these ions are positively charged and use the same ion transporter in the root membrane (Hoopen *et al*., 2010). Then excess ammonium causes a decrease in the pH of the rhizosphere so that the P element precipitates as an insoluble compound (Grandgirard *et al*., 2002).

3.7 Number of Flower

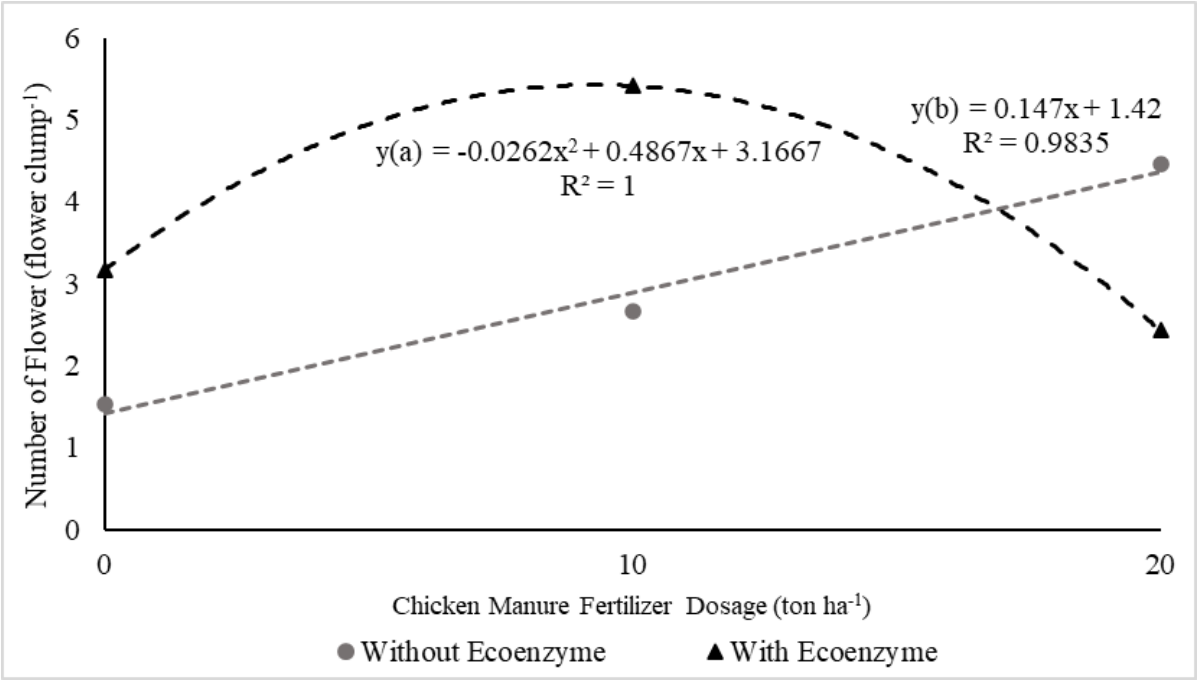
Analysis of variance conducted on the number of flower showed a significant interaction between the application frequency of ecoenzyme and chicken manure. The interaction between the number of flower due to the application frequency of ecoenzyme and chicken manure fertilizer can be seen in Table 8.

Flowers are part of the generative organs of plants. Red fountain grass flowers are in the form of long, striking purple-red feathers which are the attraction of this plant. Based on the results of the analysis of variance, it is known that the application of ecoenzyme once a week with a dose of 10 tons of chicken manure ha^{-1} can increase the number of flowers by 279.08% compared to the control treatment. The effect of the dose of chicken manure on the number of flowers at each frequency of ecoenzyme is presented in Figure 2.

Table 8. Effect of Ecoenzyme Frequency and Chicken Manure Fertilizer Dosage on the Dry Weight of Plants of Red Fountain Grass Plants

Ecoenzyme Application Frequency	Number of Flower (flower clump^{-1})		
	Chicken Manure Fertilizer Dosage (ton ha^{-1})		
	0	10	20
Without Ecoenzyme	**1,53 a**	**2,67 ab**	**4,47 bcd**
Once a week	**2,90 ab**	**5,80 d**	**2,77 ab**
Once of two week	**3,43 abc**	**5,03 cd**	**2,10 a**
HSD 5%: 2,00			

Note: Mean values with the same notation in columns and rows have no significant difference based on the 5% HSD follow-up test.



Note: (a): Application of ecoenzyme; (b): Without application of ecoenzyme

Fig 2. Effect of Manure Dose on Number of Flower at Each Frequency of Ecoenzyme Application

Based on Figure 2. shows that in the application of ecoenzyme, each additional 1 point of chicken manure dose causes the number of flowers to increase by approximately 3.62 flowers clump^{-1} (y (a) = -0.0262x2 + 0.4867x + 3.1667 with R2 = 1). However, when the dose of chicken manure increases to 20 tons ha^{-1}, the number of flowers begins to decrease. The treatment of 10 tons of chicken manure ha^{-1} produced a better number of flowers and then decreased when the dose of manure increased to 20 tons ha^{-1}. In the treatment of ecoenzyme application, the number of flowers was the highest with an R2 value of 1 so that the optimum dose of chicken manure was sought using the equation y(a)= -0.0262x2 + 0.4867x + 3.1667 and the optimum dose of chicken manure for the number of flowers was 9.28 tons ha^{-1}.

The frequency of ecoenzyme once a week and the optimal dose of chicken manure create an interactive relationship with the number of flowers. The availability of phosphorus from chicken manure can trigger flower differentiation. Phosphorus is the main component of ATP which acts as an energy source for the cell division process at the flower growth point (Khan *et al*., 2023). Without sufficient phosphorus, plants will have difficulty forming flower primordia (Brukhin and Morozova, 2011). Phosphorus in the soil is often bound to minerals such as aluminum, iron, and potassium to form insoluble compounds. With the help of organic acid ecoenzyme, phosphorus binding can be prevented because organic acid will maintain phosphorus in the form of H_2PO_4- which is easily absorbed by the roots (García-Berumen *et al*., 2025).

IV. CONCLUSION

Treatment of ecoenzyme frequency (without ecoenzyme, once a week, and once every two weeks) and chicken manure dosage (0 tons ha^{-1}, 10 tons ha^{-1}, and 20 tons ha^{-1}) on red fountain grass plants, it was concluded that there was an interaction on growth (plant length, number of leaves, leaf area, number of shoots, root volume, fresh plant weight, and dry plant weight) and flowering (number of flowers). The chicken manure dosage of 8.56 tons ha^{-1} and 9.28 tons ha^{-1} in the provision of ecoenzyme is the optimal chicken manure dosage to increase the growth and flowering of red fountain grass plants. The ecoenzyme frequency of once every two weeks is the right frequency of ecoenzyme application in increasing the growth and flowering of red fountain grass plants.

ACKNOWLEDGEMENTS

We would like to express our deepest gratitude to all parties who have contributed to the completion of this research. This research was funded by a research grant program from Brawijaya University, “Hibah Guru Besar 2025”.

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International Journal of Environment, Agriculture and Biotechnology
Vol-10, Issue-3; May-Jun, 2025
Peer-Reviewed International Journal
Journal Home Page Available: https://ijeab.com/
Journal DOI: 10.22161/ijeab

Biochemical Analysis of Tomato Plants Grafted onto Wild Brinjal Rootstocks under Fusarium-Nematode Infestation

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Received: 15 May 2025; Received in revised form: 13 Jun 2025; Accepted: 17 Jun 2025; Available online: 22 Jun 2025

Abstract— *Tomato (Solanum lycopersicum L.) cultivation is significantly constrained by the concurrent incidence of Fusarium oxysporum and Meloidogyne incognita, resulting in substantial yield losses. Grafting onto resistant rootstocks has emerged as an effective strategy to enhance resistance against these soil-borne pathogens. The present study investigated the biochemical responses of tomato plants grafted onto wild brinjal rootstocks under Fusarium-nematode infested conditions. Among several rootstocks screened in the screenhouse, brinjal roostock RB_5 (Solanum torvum) and RB_3 (a wild brinjal genotype) were identified as the most effective. RB_5 exhibited the highest phenol content (0.420 mg/g FW in roots; 0.349 mg/g FW in stems) and peroxidase activity (2.19 µmol/min/g FW in roots; 1.47 µmol/min/g FW in stems). These biochemical substances are associated with enhanced structural defense and regulation of oxidative stress, contributing to increased resistance. Grafting tomato plants onto resistant wild rootstocks, particularly S. torvum (RB_5), significantly strengthens biochemical defense mechanisms under Fusarium–nematode stress. This approach offers a sustainable, eco-friendly alternative to chemical control, improving plant resilience and supporting higher productivity in Fusarium-nematode infested soils.*

Keywords— ***Biochemical defense, Grafting, Rootstock, Solanum lycopersicum***

I. INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is one of the most widely cultivated vegetable crops globally, valued for its nutritional and economic significance. However, its productivity is severely constrained by soil-borne pathogens, particularly *Fusarium oxysporum* and root-knot nematodes (*Meloidogyne* spp.), which often occur simultaneously, leading to synergistic detrimental effects on plant health and yield (Meshram and Adhikari, 2024). These biotic stresses induce complex physiological and biochemical responses in plants, affecting their defense mechanisms and oxidative stress regulation. Grafting has emerged as an effective strategy to enhance tolerance against soil-borne pathogens by combining disease-resistant rootstocks with high-yielding scions (Phani *et al*., 2024). Rootstocks such as brinjal (*Solanum melongena*) and resistant tomato cultivars have shown potential in mitigating the adverse effects of Fusarium-nematode complexes. Understanding the biochemical changes induced in grafted plants under such stress is critical for elucidating resistance mechanisms. In this study, the defense responses and stress tolerance of grafted and non-grafted plants were assessed through the analysis of key biochemical parameters: total phenol content (mg/g fresh weight) and peroxidase activity (µmol) in both roots and shoots. These specific substances were chosen due to their pivotal and well-established roles in mediating plant defense mechanisms and serving as reliable indicators of resistance against biotic and abiotic stresses.The findings are expected to contribute to the development of grafting-

based strategies for sustainable tomato production in Fusarium-nematode infested soils.

II. MATERIAL AND METHODS

The present study was conducted in the screen-house of the Department of Nematology, CCS Haryana Agricultural University, Hisar. Two resistant rootstock genotypes, RB_3 (wild) and RB_5 (*Solanum torvum)* were utilised for grafting. Three tomato cultivars, namely Pusa Ruby (S_1), Punjab Gaurav (S_2), and a locally grown polyhouse variety (S_3), were selected as scions. These were grafted onto the rootstocks to develop six graft combinations: $RB_3 \times S_1$, $RB_3 \times S_2$, $RB_3 \times S_3$, $RB_5 \times S_1$, $RB_5 \times S_2$, and $RB_5 \times S_3$. All treatments, including grafted and non-grafted plants, were maintained under infested conditions of *Fusarium oxysporum* and *Meloidogyne incognita*. The experimental setup followed a Completely Randomized Design (CRD) with four replications per treatment. For data collection, five tomato plants were randomly selected from each replication. Biochemical analyses, including total phenol content and peroxidase activity in both roots and shoots, were performed using standard protocols. The total phenol content (mg/g fresh weight) of the roots showing resistant reaction was estimated by the method of Swain and Hillis (1959) and Peroxidase activity (U/min/g FW) was assayed as per the method of Machly (1954). Data were statistically analyzed using two-factor ANOVA with the aid of OPSTAT software.

Brinjal Rootstock RB_5 Brinjal Rootstock RB_3

Fig. 1: Resistant rootstocks of brinjal selected from screening against fusarium nematode complex for tomato grafting

III. RESULT AND DISCUSSION

In this study, biochemical mechanisms in roots and stems of grafted and non-grafted plants were established by analysing total phenol content and enzymes, *viz*., peroxidases under fusarium-nematode infested conditions. Phenolic compounds play a major role in the defense mechanism of plants against various infectious agents. The present study indicated that the rootstocks had a significant effect on total phenol content in roots and stems (mg/g FW). Among the evaluated rootstocks, RB_5 consistently demonstrated the highest phenol accumulation, recording 0.420 mg/g FW in roots (Table 1) and 0.349 mg/g FW in scion stems (Table 2). Conversely, the non-grafted scions (R_0) exhibited the lowest phenol content, with values of 0.311 mg/g FW in roots (Table 1) and 0.247 mg/g FW in scion stems (Table 2). However, all the scions and interaction between rootstocks and scions had non-significant effect on phenol content in roots and stems.

The higher total phenol content observed in grafted plants may help control root-knot nematode and fusarium wilt under infested conditions. Bajaj *et al*. (1983) stated that total phenol content in roots and stems indicated the level of resistance against root-knot nematodes in tomato. Total phenol content in roots also showed a negative association with root-knot index, as well as number of galls and number of egg masses per root system. Mahajan *et al*. (1985) also reported the nematicidal activity of phenolic compounds. The post-infection increases in phenols, accumulating at infection sites, likely contribute to the plant's defense mechanism by disrupting pathogen metabolic activities, leading to increased root length (Gopinatha *et al*., 2002). Naik *et al*. (2024) similarly reported an accumulation of higher phenolics in plants subjected to stress conditions, reinforcing the role of these compounds in plant defense.

Table 1: Effect of rootstocks, scions and their interactions on total phenol content in roots (mg/g fresh weight) under fusarium-nematode infested conditions

Scion (B) / Rootstock (A)	Pusa Ruby (S_1)	Punjab Gaurav (S_2)	Polyhouse LC (S_3)	Mean A
RB_5	0.413	0.426	0.420	0.420
RB_3	0.396	0.405	0.401	0.401
*R_0	0.301	0.323	0.308	0.311
Mean B	0.370	0.385	0.376	
CD at 5% level of significance				
Factor A (treatment)= 0.02				
Factor B (rootstock)= NS				
Factor A×B= NS				

*Non-grafted scions

Table 2: Effect of rootstocks, scions and their interactions on total phenol content in scion Stems (mg/g fresh weight) under fusarium-nematode infested conditions

Scion (B) / Rootstock (A)	Pusa Ruby (S_1)	Punjab Gaurav (S_2)	Polyhouse LC (S_3)	Mean A
RB_5	0.345	0.353	0.349	0.349
RB_3	0.310	0.324	0.322	0.319
*R_0	0.243	0.251	0.246	0.247
Mean B	0.299	0.309	0.306	
CD at 5% level of significance				
Factor A (treatment)= 0.032				
Factor B (rootstock)= NS				
Factor A×B= NS				

*Non-grafted scions

The enzyme peroxidase is intrinsically linked to plant defense mechanism by catalyzing the condensation of phenolic compounds into lignin. The current model suggests that peroxidase aids in defense by converting phenolic monomers from the phenylpropanoid pathway into insoluble polymers (Robb *et al*, 1991). It has been demonstrated that peroxidase plays an important, early and specific role in hypersensitive containment of the pathogen (Peng and Kuc, 1992). Estimation of peroxidase activity in the present study indicates that all the resistant rootstocks possessed higher peroxidase activity than the susceptible ones. Specifically, rootstock RB_5 showed the highest peroxidase activity in roots, *i.e.,* 2.19 µmol (Table 3) and stems, *i.e*., 1.47 µmol (Table 4), whereas non-grafted scions (R_0) exhibited the minimum activity of 1.01 µmol in roots (Table 3) and at 0.71 µmol in stems (Table 4). Consistent with phenol content, peroxidase activity varied non-significantly among scions and their interactions with rootstocks. Peroxidase activity was found to be higher in all resistant rootstocks compared to the susceptible ones, with RB_5 showing the maximum levels. These observations align with earlier studies reporting the role of peroxidase in induced systemic resistance across plant species (Hammerschmidt *et al*., 1982; Dalisay and Kuc, 1995; Ramamoorthy and Samiyappan, 2001). Similar findings were also reported by Rani *et al*. (2008) and Sundhariaya (2008) in tomato, and Sherly (2010) in *Solanum* species.

Table 3: Effect of rootstocks, scions and their interactions on peroxidases (U/min/g FW) in roots under fusarium-nematode infested conditions

Scion (B) / Rootstock (A)	Pusa Ruby (S_1)	Punjab Gaurav (S_2)	Polyhouse LC (S_3)	Mean A
RB_5	2.13	2.26	2.19	2.19
RB_3	1.91	1.97	1.95	1.94
*R_0	0.98	1.05	1.01	1.01
Mean B	1.67	1.76	1.71	
CD at 5% level of significance				
Factor A (rootstock)= 0.11				
Factor B (scion)= NS				
Factor A×B= NS				

*Non-grafted scions

Table 4: Effect of rootstocks, scions and their interactions on peroxidases (U/min/g FW) in scion Stems under fusarium-nematode infested conditions

Scion (B) / Rootstock (A)	Pusa Ruby (S_1)	Punjab Gaurav (S_2)	Polyhouse LC (S_3)	Mean A
RB_5	1.44	1.52	1.46	1.47
RB_3	1.10	1.26	1.14	1.16
*R_0	0.67	0.75	0.71	0.71
Mean B	1.07	1.17	1.10	
CD at 5% level of significance				
Factor A (rootstock)= 0.09				
Factor B (scion)= NS				
Factor A×B= NS				

*Non-grafted scions

IV. CONCLUSION

This biochemical analysis revealed that grafting tomato plants onto resistant wild rootstocks particularly with brinjal rootstocks RB_5, induced elevated levels of total phenol content and increased activity of crucial defense enzymes such as peroxidases. These observed biochemical alterations underscore the enhanced intrinsic defense mechanisms and improved physiological performance of grafted plants, leading to robust resistance against the devastating Fusarium-nematode complex under infested conditions. Consequently, this sustainable grafting strategy offers a viable and eco-friendly approach to mitigate soil-borne pathogen pressures, reduce dependency on chemical controls, and ultimately bolster crop resilience, yield, and overall plant health in tomato cultivation.

V. AUTHORS' CONTRIBUTION

Conceptualization of research (IA and KY); Designing of the experiments (IA and KY); Contribution of experimental materials (IA and KY); Execution of field/lab experiments and data collection (KY and AK); Analysis of data and interpretation (KY, K, VK and PP); Preparation of the manuscript (KY, SK and PP)

VI. DECLARATION

The authors declare that there is no conflict of interest.

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International Journal of Environment, Agriculture and Biotechnology
Vol-10, Issue-3; May-Jun, 2025
Peer-Reviewed International Journal
Journal Home Page Available: https://ijeab.com/
Journal DOI: 10.22161/ijeab

Seasonal Abundance and Population Dynamics of *Chrysoperla* spp. in Tomato Agroecosystems

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Received: 11 May 2025; Received in revised form: 09 Jun 2025; Accepted: 15 Jun 2025; Available online: 22 Jun 2025

Abstract— *The study investigated the seasonal abundance and population dynamics of Chrysoperla spp. on tomato crops across two consecutive years, focusing on the influence of environmental factors and prey availability. Observations revealed distinct peaks in egg (4.2 eggs/plant in the 16th SMW, 2023; 1.6 eggs/plant in the 16th SMW, 2024) and larval densities (2.4 larvae/plant in the 16th SMW, 2023; 2.0 larvae/plant in the 15th SMW, 2024). Maximum and minimum temperatures positively correlated with egg (r=0.492*), larval (r=0.662**), and pupal (r=0.504*) stages, while high morning and evening relative humidity negatively impacted all developmental stages. Adult populations showed moderate peaks (0.6 adults/plant in 16th SMW, 2023; 19th SMW, 2024) but were also constrained by high humidity levels. Prey availability, particularly whitefly and jassid populations, exhibited a supplementary role in supporting larval development. Comparisons with previous studies revealed consistent trends, with optimal temperatures and low humidity favouring Chrysoperla populations, while excessive moisture inhibited their activity. The study emphasises the importance of temperature and prey abundance in regulating Chrysoperla population dynamics, underscoring its significant role as a biological control agent in tomato agroecosystems. Integrating Chrysoperla into Integrated Pest Management (IPM) strategies, alongside climate-optimized practices, can effectively enhance pest suppression and ensure sustainable crop protection.*

Keywords— ***Chrysoperla zastrowi sillemi, Tomato, Seasonal abundance, Environmental factors, Biological control, Pest management, Population dynamics.***

I. INTRODUCTION

Green lacewings, often called "golden eyes" and "aphid lions," are renowned biocontrol agents in the order Neuroptera. Their larvae are voracious predators, capable of consuming over 300 aphids in their lifetime, while adults primarily feed on nectar, honeydew, and pollen, enhancing their survival and fecundity (Legaspi *et al.,* 1994; Michaud, 2001; Villenave *et al.,* 2006). In India, *Chrysoperla zastrowi sillemi*, formerly known as *C. carnea*, is the most dominant and economically significant species, exhibiting a broad host range, insecticide resistance, and adaptability to diverse ecosystems (Henry *et al.,* 2010; Hemalatha *et al.,* 2014; Gonzalez *et al.,* 2015). Their ability to thrive across varied environmental conditions, combined with ease of mass-rearing and strong predatory efficiency against soft-bodied pests like aphids, jassids, and mites, makes them an essential component of sustainable Integrated Pest Management (IPM) strategies (Pappas *et al.,* 2011). Furthermore, their role in reducing chemical pesticide dependence highlights their ecological and economic importance in modern agriculture (Wäckers and van Rijn, 2012; Gonzalez *et al.,* 2015).

II. MATERIAL AND METHOD

Present study on seasonal abundance of *Chrysoperla* spp. was conducted at the Research Farm of the Department of Entomology, CCS HAU, Hisar, from 2022–2024. Hisar is located at 29.1492° N latitude and 75.7217° E longitude, with an elevation of 215 m above sea level. The region experiences extreme weather conditions, with summer temperatures reaching 40–46°C, winter temperatures dropping to 1.5–4°C, and rainfall primarily occurring during the Southwest monsoon and winter western disturbances. The area is also occasionally affected by strong winds and intermittent dust storms. The present study was conducted to assess the seasonal abundance and population dynamics of *Chrysoperla* spp. in tomato during the summer season. Tomato was selected as a representative crop to study the predator-prey interactions and the influence of environmental factors on *Chrysoperla* spp. abundance. The crop provided a suitable host environment and consistent prey availability, allowing a detailed analysis of population trends across different growth stages and seasonal conditions. For tomato, 30 representative plants were randomly selected for weekly observations throughout the study period. Monitoring was systematically conducted to record the different developmental stages of *Chrysoperla* spp.—eggs, larvae, pupae, and adults—along with their density and distribution on the selected plants. The population of major sucking pests, *i.e.* whitefly was also recorded to understand predator-prey interactions and their seasonal trends. Weekly data collection included critical weather parameters such as maximum and minimum temperatures, morning and evening relative humidity, rainfall, rainy days, and sunshine hours. These parameters were meticulously documented and analysed to identify their correlation with the seasonal abundance of *Chrysoperla spp.* in the tomato crop. Pearson's correlation coefficient was used to analyse the relationship between weather variables, prey populations, and different life stages of *Chrysoperla spp.* Statistical analysis was performed using a software package developed by CCS HAU, Hisar, ensuring precise and reliable interpretation of the data.

Pearson's correlation coefficient: $r = \frac{n(\sum xy)-(\sum x)(y)}{\sqrt{[n(\sum x^2)-(\sum x^2)][n(\sum y^2)-(\sum y^2)]}}$

III. RESULTS AND DISCUSSION

The seasonal abundance and population dynamics of *Chrysoperla* spp. on tomato crops revealed distinct trends influenced by environmental conditions and prey availability across two growing seasons. In 2023 (Table 1), eggs were first observed in the 13th SMW, peaking at 4.2 eggs per plant in the 16th SMW under favourable conditions of 38.1°C maximum temperature, 21.2°C minimum temperature, and 8.2 hours of bright sunshine. In 2024, eggs appeared earlier in the 12th SMW, with densities reaching their highest at 1.6 eggs per plant in the 16th SMW under slightly lower temperatures and reduced sunshine hours. Larval populations followed a similar trend, appearing in the 13th SMW in 2023 and the 12th SMW in 2024, with peak densities recorded in the 16th SMW (2.4 larvae per plant) and the 15th SMW (2.0 larvae per plant), respectively. Pupal densities were comparatively lower, peaking at 0.4 pupae per plant in the 16th and 17th SMWs in 2023 and slightly earlier in the 10th SMW in 2024 (0.6 pupae per plant). Adult populations were also influenced by weather parameters, showing peaks of 0.6 adults per plant in the 16th SMW (2023) and the 19th SMW (2024). These findings align with observations by Mari *et al.* (2013), who reported peak *Chrysoperla carnea* densities at 1.52 individuals per plant during mid-March under temperatures around 36°C and dry weather conditions, indicating the importance of warm temperatures and low humidity in supporting predator abundance.

Weather variables played a significant role in determining the population trends of *Chrysoperla* spp. across both years (Table 2). Eggs exhibited positive correlations with maximum temperature in 2023 (r = 0.492*) and minimum temperature in 2024 (r = 0.634**), while morning (r = -0.591*) and evening relative humidity (r = -0.675**) negatively affected their abundance. Larvae showed strong positive correlations with both maximum (r = 0.662** in 2023, r = 0.581* in 2024) and minimum temperatures (r = 0.717** in 2023, r = 0.794** in 2024), while high morning (r = -0.592* in 2023, r = -0.810** in 2024) and evening humidity (r = -0.487* in 2023, r = -0.808** in 2024) limited their activity and survival. Similar findings by Nair et al. (2020) demonstrated that larvae thrive best under moderate humidity and temperatures ranging between 28–35°C, reinforcing the strong dependence of larval activity on optimal environmental conditions.

Pupal densities in the present study remained low (Table 1), with peak densities of 0.4–0.6 pupae per plant. Positive correlations with maximum and minimum temperatures suggest that dry, warm conditions favor pupation, while high humidity negatively impacts pupal survival. This agrees with Sreedhar et al. (2019), who observed similar trends, emphasizing that pupal survival is highly sensitive to excessive humidity. Furthermore, Singh (2017) highlighted that pupal success largely depends on consistent temperature conditions without abrupt fluctuations, which aligns with the observed patterns in our study.

Adult densities showed positive correlations with maximum (r = 0.564**) and minimum (r = 0.676**) temperatures (Table 2), with morning humidity negatively impacting adult abundance. Similar findings were reported by Duelli (2001), who emphasized the importance of stable temperature regimes for adult *Chrysoperla* survival and oviposition activity. Additionally, Singh et al. (2017) noted that adult *Chrysoperla* populations thrive in environments with reduced humidity and consistent sunshine hours, aligning with the patterns observed in our study.

Prey availability (Table 2), particularly whitefly, played a secondary yet supportive role in influencing *Chrysoperla* populations. While larval and adult stages depend on prey for growth and reproduction, their population patterns appeared more closely tied to weather parameters than prey abundance alone. This observation resonates with findings from Nair et al. (2020), who highlighted the efficiency of *Chrysoperla* larvae in suppressing aphid and whitefly populations in tomato ecosystems. Our study similarly observed a moderate but significant correlation between prey density and larval abundance, reinforcing the role of prey as a supplementary factor influencing predator dynamics.

In summary, the synchronized peaks of *Chrysoperla* eggs, larvae, pupae, and adults with favourable environmental conditions emphasize their adaptability to fluctuating weather patterns. Eggs peaked in the 16th SMW, larvae displayed their highest densities in the 15th–16th SMWs, and adults peaked slightly later, indicating a natural progression of population stages. These findings align with earlier studies by Mari et al. (2013) and Nair et al. (2020) highlighting the importance of temperature, relative humidity, and prey availability in shaping *Chrysoperla* population dynamics. Such insights contribute to a deeper understanding of *Chrysoperla zastrowi sillemi* ecology and its integration into sustainable pest management programs, reinforcing its potential as a reliable predator in tomato agroecosystems.

Table 1: Seasonal abundance of different stages of Chrysoperla spp. on tomato under field conditions during 2023 and 2024

SMW	1st year (2023)				2nd year (2024)			
	Egg	Larvae	Pupa	Adult	Egg	Larvae	Pupa	Adult
12	0	0	0	0.2	0.4	0.6	0	0
13	0.2	0.4	0	0	0.2	1.2	0	0.4
14	0.4	0.6	0.2	0	0.8	0.6	0	0
15	0.6	1.2	0	0	1.2	2.0	0.2	0.2
16	4.2	2.4	0.4	0.6	1.6	0.2	0.2	0.2
17	0.4	1.2	0.4	0.2	0.2	1.4	0	0
18	0.2	0.8	0.2	0.2	1.4	1.0	0	0
19	0.2	0.2	0	0	0.2	1.4	0.6	0.6

SMW: Standard Meteorological Weeks

Table 2: Correlation of Chrysoperla spp. population with weather parameters and pest population on tomato under field conditions during year 2023 and 2024

Weather parameters	1st year (2023)				2nd year (2024)			
	Stages of *Chrysoperla* spp.							
	Eggs	Larvae	Pupae	Adults	Eggs	Larvae	Pupae	Adults
Max. Temp. (°C)	0.492*	0.662**	0.504*	0.434	0.175	0.581*	0.832**	0.564**
Min. Temp. (°C)	0.478	0.717**	0.595*	0.541*	0.634**	0.794**	0.519*	0676**
R.H. Morning (%)	-0.357	-0.592*	-0.505*	-0.317	0.591*	0.810**	-0.642**	0.417*
R.H. Evening (%)	-0.247	-0.487*	-0.507*	-0.186	-0.675**	-0.808**	-0.553*	-0.457
Bright Sunshine Hours	0.301	0.416	0.445	0.123	-0.632**	-0.630**	-0.341	-0.368
Rainfall (mm)	0.003	-0.043	0.022	0.016	0.422	0.491*	0.298	0.311
Rainy Days	-0.162	-0.199	-0.145	-0.129	-0.213	-0.196	-0.137	-0.172
Whitefly	0.293	0.376	0.273	0.197	0.33	-0.137	-0.406	-0.179

*Significance at 5% ** Significance at 1%

IV. CONCLUSION

The study revealed that *Chrysoperla zastrowi sillemi* populations on tomato crops are significantly influenced by environmental factors, particularly temperature, relative humidity, and sunshine hours. Egg and larval densities peaked under warm, dry conditions, while high humidity negatively impacted survival and activity across all life stages. These findings highlight the importance of optimizing environmental conditions and prey availability to maximize the biocontrol potential of *Chrysoperla zastrowi sillemi* in tomato agroecosystems, reinforcing its role in sustainable Integrated Pest Management (IPM) strategies.

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International Journal of Environment, Agriculture and Biotechnology
Vol-10, Issue-3; May-Jun, 2025
Peer-Reviewed International Journal
Journal Home Page Available: https://ijeab.com/
Journal DOI: 10.22161/ijeab

Proximate Composition and Functional Enhancement of *Panjiri* through Giloy (Tinospora cordifolia) Stem Supplementation

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Received: 20 May 2025; Received in revised form: 15 Jun 2025; Accepted: 21 Jun 2025; Available online: 26 Jun 2025

Abstract— *The present investigation was carried out to develop and standardize value added* panjiri *by incorporating giloy (*Tinospora cordifolia*) stem powder at varying concentrations of 5, 10, and 15 per cent. Traditional* panjiri*, a nutrient-dense Indian sweet prepared using wheat flour, ghee, sugar, dry fruits, and aromatic spices, holds cultural and medicinal significance, particularly during the winter season and for lactating mothers. In this study, giloy stem powder—renowned in ayurveda for its therapeutic properties—was selected for its rich bioactive profile and high medicinal value, especially concentrated in the stem. The present study aim was to enhance the nutritional and functional properties of* panjiri *through herbal supplementation. Among the three supplemented formulations, Type-I* panjiri *containing 5 per cent giloy stem powder was found to be the most organoleptically acceptable. The proximate composition of this formulation revealed moisture content of 2.82 per cent, crude protein 5.84 per cent, crude fat 24.16 per cent, crude fibre 1.73 per cent, and ash content 2.51 per cent. The findings suggest that incorporating medicinal plant extracts such as giloy into traditional foods can improve both their therapeutic potential and nutritional profile, offering a novel approach to functional food development.*

Keywords— ***Gioly, Panjiri, health benefits, supplemented panjiri, giloy stem***

I. INTRODUCTION

Medicinal plants are now seen as valuable health supplements due to their proven nutritional and therapeutic properties and low or non-existent toxicity compared to modern pharmaceuticals and synthetic or semi-synthetic supplements (Semwal *et al.,*2024). Tinospora cordifolia is one such medicinal plant which is a semi-evergreen, deciduous climbing shrub commonly located on the trunks of large trees such as mango and neem. It is capable of thriving in various soil types, ranging from acidic to basic, under conditions of average moisture (Singh et al., 2003). The stems of the plant exhibit moisture and thickness, featuring prominent aerial roots that extend from the branches with differing diameters. The younger stems are characterized by a green hue and smooth surfaces, whereas the older stems present a light brown coloration (Sardhara & Gopal, 2013). Though different plant parts have several medicinal properties (Singh et al., 2025). But this research aims to unearth medicinal values of stem and how its incorporation in a traditional Indian food item called *panjiri* enhances the overall health benefits of the eatable product. Creating novel foods with additional health benefits can be a great boost to marketing of that product (Gawade et al., 2023).

II. REVIEW OF LITERATURE

Verma et al., (2021) revealed that giloy is beneficent in ailments like diabetes, stomach ache, jaundice also in skin and stomach disorders. In similar way Jayswal, (2021) described about windfalls of this plant also stating that it is also called Amrita. Specially

mentioned its perks in being effective in various 21st century diseases like corona virus, swine flu as it is general immunity booster. As it is a climber plant it is said if it climbs neem tree then medicinal properties get boost up. Sodha (2025) mentioned its indulgences in prevention several chronic diseases; also added fringes in this plant being a cure for malaria, urinary tract infections but also bright to limelight that it can be antagonistic to people suffering from autoimmune diseases and it can cause constipation in some people. Sharma et al. (2025) found various components contained in giloy plant like vitamins, proteins, fibre, carbohydrates etc. due to which this plant was used to cure inflammation, cancer, HIV etc.

III. MATERIALS AND METHODS

Procurement of materials: Giloy (Tinospora Cordiofolia) stem was harvested from nearest locally available sources. Other ingredients required for the preparation of value-added products and packaging material was purchased from the local market in a single lot.

Processing of giloy stem: The giloy stem was thoroughly washed with tap and distilled water to remove adhering impurities. Stem was cut into small pieces. Stem was dried in hot air oven at 50±5^{O}C. Then the dried stem was powdered, passed through 60 mesh sieve and stored in an air tight container till further use. Other ingredients were stored in the LDPE package until further use.

Fig.1: Giloy stem

Food products mixed with giloy stem powder: *Panjiri* was standardized and developed by adding giloy stem powder at different proportions in standard recipes.

Fig.2: Panjiri developed by adding giloy stem powder

Panjiri

Ingredients	Amount
Wheat Flour	100 g
Ghee	30 g
Sugar	30 g

Method of preparations:

1. Sieved wheat flour.
2. Roasted wheat flour in ghee till light brown.
3. Allowed to cool slightly.
4. Added the powdered sugar and mixed thoroughly.
5. Stored in air tight container.
6. In type-1, type-II and type-III panjiri wheat flour was substituted with 5, 10 and 15 gm of giloy stem powder.

Nutritional evaluation of *panjiri* developed using *Giloy* stem powder

Proximate composition

Proximate composition *viz,* moisture, crude fat, crude fiber, crude protein, total ash and carbohydrate of *panjiri* were determined by standard procedures given by AOAC (2000). All the analysis was done in triplicates.

Moisture: To estimate moisture content, the AOAC (2000) method was employed. A sample of two gram of *panjiri* was weighed and placed in a clean, dry, and weighed aluminum dish (dried at 130 ± 3°C for 20 minutes). The sample was dried in a hot air oven at 130 ± 3°C for approximately 1 hour until it attained an uniform weight, then cooled in a desiccator. Weight loss was then estimated as a percentage of moisture content:

$$\text{Moisture (\%)} = \frac{\text{Loss in weight}}{\text{Weight of sample}} \text{x} 100$$

Crude protein: Crude protein was analysed by standard method of analysis (AOAC, 2000), using KEL PLUS Automatic Nitrogen Estimation System. A factor of 6.25 was applied to convert the amount of nitrogen to crude protein.

Digestion

A 1 g sample was combined with 25 ml of concentrated sulfuric acid and 3 g of digestion mixture, then heated at 420 °C in a digestion unit. The mixture was considered fully digested when it turned bluish-green and visible flames subsided, typically within 1–2 hours. If needed, an additional 15 minutes of heating was applied. After digestion, the tubes were cooled for 15 minutes on a stand before proceeding.

Distillation

To determine nitrogen content, the digested sample was treated with 40 per cent sodium hydroxide in a Kjeldahl distillation unit. Released ammonia was captured in 10 ml boric acid with mixed indicator and titrated using N/100 hydrochloric acid. A distinct color change marked the end point.

$$\text{Total N (\%)} = \frac{14 \times \text{Titrant value} \times \text{Normality of acid}}{1000 \times \text{sample weight (g)}} \times 100$$

Where,

Titrant value = Volume of N/100 HCl used for titration.

Crude Fat Estimation

Crude fat content in the stem was determined using the AOAC (2000) method with an Automatic SOCS Plus Solvent Extraction Apparatus.

Procedure

Clean, dry extraction beakers were weighed before use. Two grams of moisture-free sample was placed in a pre-weighed thimble and inserted into the beaker containing ~100 ml petroleum ether (boiling point 60–80 °C). Extraction was performed at 100 °C for one hour. Post-extraction, the solvent was recovered by raising the temperature to 120 °C. Beakers containing extracted fat were dried in a hot air oven at 60 °C until constant weight, then cooled in a desiccator and reweighed. Crude fat content was calculated based on the weight difference.

$$\text{Fat (\%)} = \frac{W_2 - W_1}{W} \times 100$$

Where,

W = Weight of sample (g)

W_1 = Weight of empty beaker

W_2 = Weight of beaker with fat

Crude Fiber Estimation: Crude fiber was determined following the AOAC (2000) standard method.

Procedure

A 1 g fat-free, oven-dried sample was boiled with 200 ml of 1.25% H_2SO_4 and a few drops of antifoaming agent for 30 minutes using a crude fiber apparatus. The mixture was filtered through a Buchner funnel, and the residue was boiled again for 30 minutes with 200 ml of 1.25% NaOH. The insoluble material was filtered, thoroughly washed with hot water, followed by ethanol (twice) and acetone (three times), then dried at 100 °C to constant weight. The dried residue was ashed in a muffle furnace at 550 °C for 1 hour, cooled in a desiccator, and weighed to determine crude fiber content.

$$\text{Crude fiber (\%)} = \frac{W2 - W3}{W1} X\ 100$$

Where,

W1 = Weight of sample (g)

W2 = Weight of insoluble matter (wt. of crucible + insoluble matter– wt. of crucible)

W3 = Weight of ash (wt. of crucible + wt. of ash – wt. of crucible)

Total Ash: Ash was determined following AOAC (2000) guidelines. Five grams of oven-dried sample were placed in a silica crucible and pre-ignited to remove charred material. The crucible was then heated in a muffle furnace at 500 °C for 5 hours or until white ash formed. After cooling in a desiccator, the crucible was weighed. The remaining residue represented the ash content.

IV. RESULT AND DISCUSSION

Table 1 shows proximate composition of *panjiri,* developed using giloy stem powder (%, on dry weight basis)

Treatment	Moisture (g/100g)	Crude Protein (g/100g)	Crude Fat (g/100g)	Crude Fibre (g/100g)	Ash (g/100g)
Control (WF:100)	2.76 ± 0.06^{d}	7.33 ± 0.20^{a}	24.63 ± 0.01^{a}	1.18 ± 0.04^{c}	2.21 ± 0.08^{a}
Type-I	2.82 ± 0.05^{c}	5.84 ± 0.01^{b}	24.16 ± 0.32^{a}	1.73 ± 0.15^{bc}	2.51 ± 0.19^{a}
Type-II	3.05 ± 0.04^{b}	4.92 ± 0.04^{c}	23.66 ± 0.17^{b}	2.78 ± 0.11^{b}	2.78 ± 0.48^{a}
Type-III	3.15 ± 0.05^{a}	4.67 ± 0.05^{c}	22.85 ± 0.09^{c}	3.93 ± 0.08^{a}	3.93 ± 0.07^{b}
C.D. (*P<0.05*)	0.16	0.36	0.62	0.34	0.88

Table 1 presents the composition of control wheat flour *panjiri* and giloy stem incorporated *panjiri*. The incorporation of (Giloy Stem Powder) GSP in *panjiri* showed a significant ($p<0.05$) effect on proximate compositions. Moisture content in 100 per cent wheat flour *panjiri* (control) was 2.76 g/100g, while that of type-I,

type-II, and type-III supplemented *panjiri* were 2.82, 3.05, and 3.15 g/100g, respectively. Concentration of GSP in type-I, type-II, and type-III increased following this pattern- 5, 10 and 15 per cent respectively (Figure 3). The crude protein content in control *panjiri* was 7.33 g/100g, which was significantly ($p \leq 0.05$) higher than type-I (5.84 g/100g), type-II (4.92 g/100g) and type-III (4.67 g/100g) GSP-supplemented *panjiri*. However, it was observed that the protein content of type-III was significantly ($P \leq 0.05$) lower than that of type-I and type-II (Figure 4).

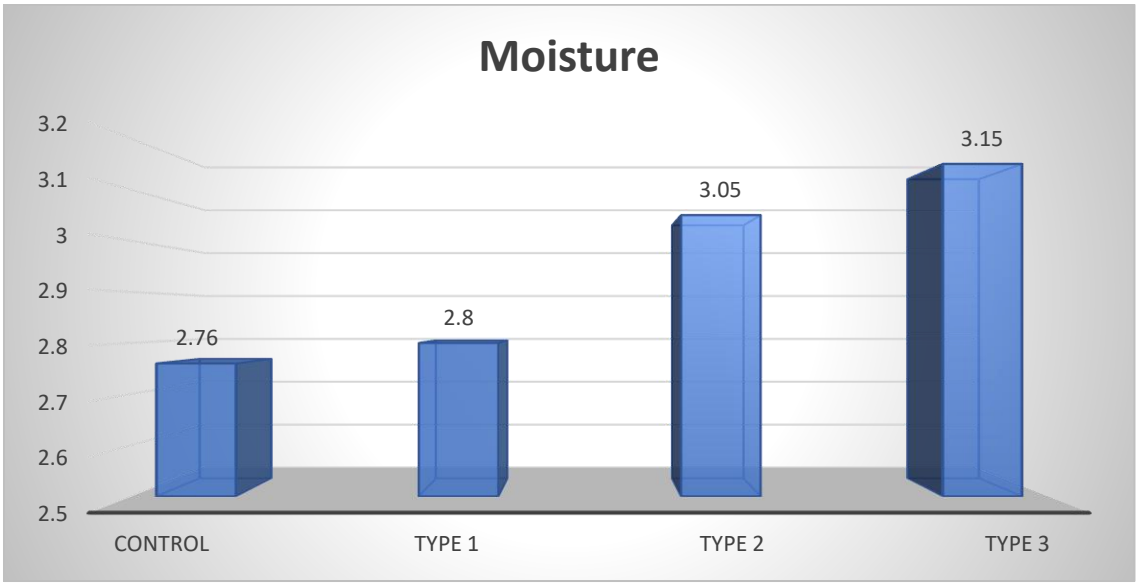

Fig.3: Moisture content of panjiri

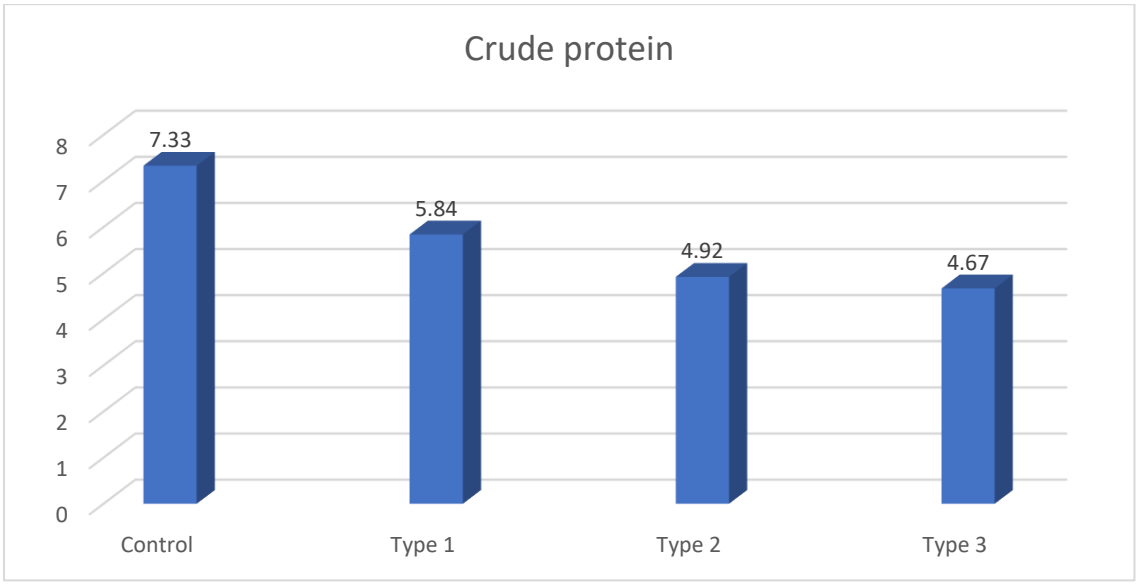

Fig.4: Crude protein content of panjiri

The fat content in control *panjiri* was 24.63 g/100g, which was significantly higher than that of type-II (23.66 g/100g) and type-III (22.85 g/100g) *panjiri*. The fat content in type-I (24.16 g/100g) was not significantly different from control (Figure 5).

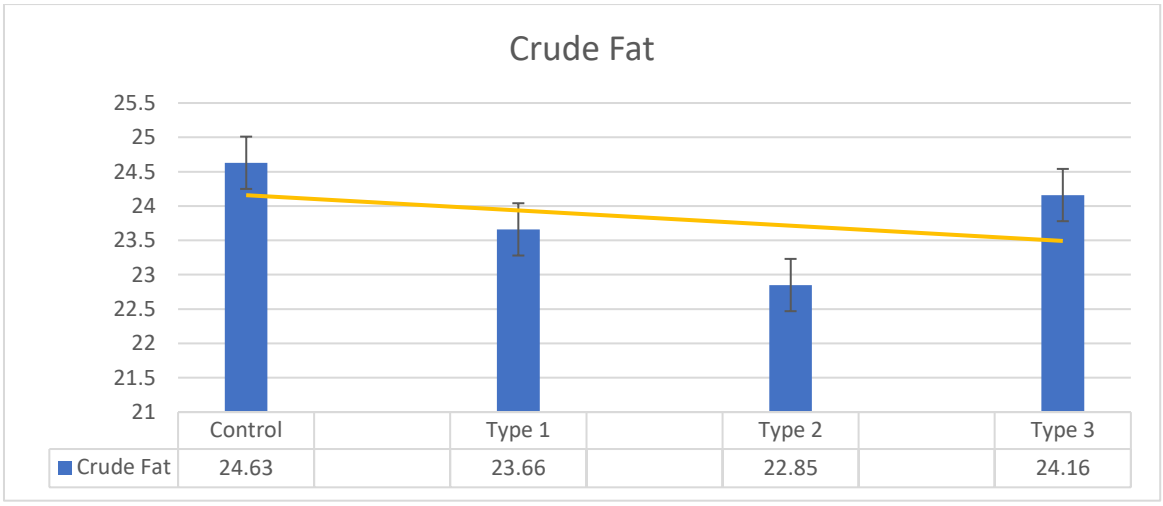

Fig.5: Crude fat content of panjiri

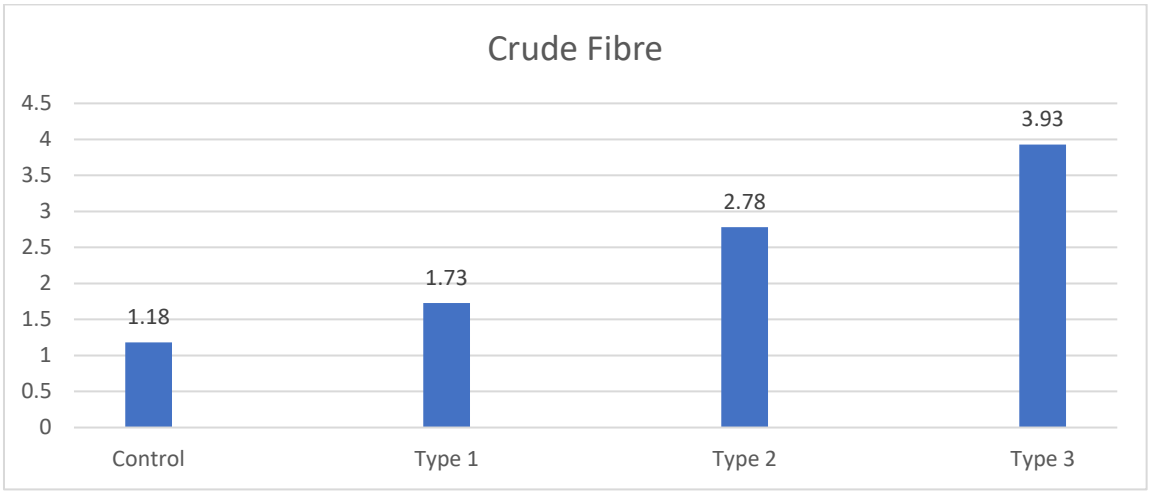

Fig.6: Crude fiber content of panjiri

The crude fibre content of control *panjiri* was 1.18 g/100g, which increased significantly in type-I (1.73 g/100g), type-II (2.78 g/100g), and type-III (3.93 g/100g), respectively. Concentration of GSP in type-I, type-II, and type-III increased following this pattern- 5%, 10% and 15% respectively. (Figure 6).

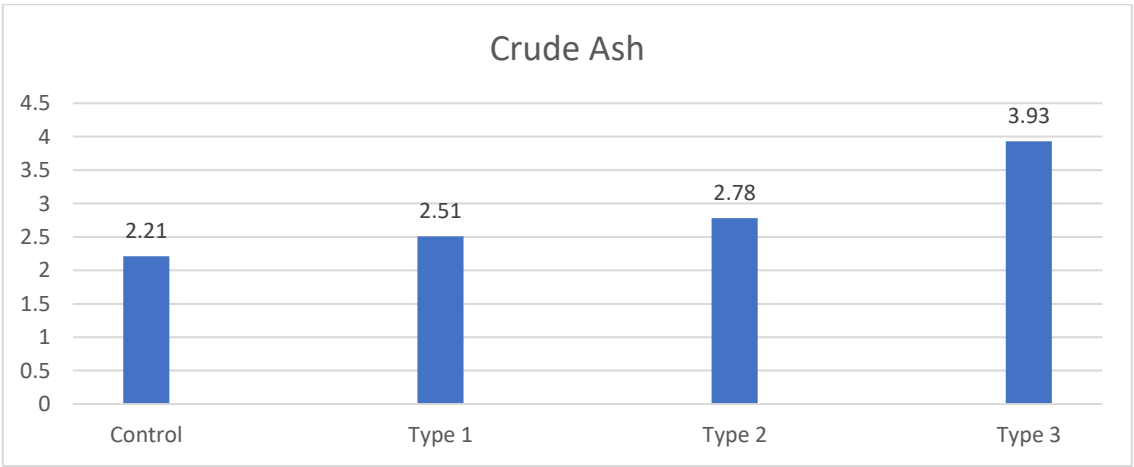

Fig.7: Ash content of panjiri

The ash content of control, type-I, type-II, and type-III *panjiri* was 2.21, 2.51, 2.78, and 3.93 g/100g, respectively. However, no significant difference ($p>0.05$) was observed in ash content between control and type-I, type-II *panjiri*, while type-III showed a significant increase ($p<0.05$) (Figure 7).

Discussion: In Indian culture, *panjiri* is a widely consumed traditional snack, valued for its long shelf-life and palatable composition due to its sugar and fat content, similar to how cookies are consumed in Western or modern urban cultures (Okpala & Okoli, 2012). Despite modernization, *panjiri* remains especially popular in rural India (Vijayaraghavan & Rao, 1998). This study focused on the development of *giloy*-supplemented *panjiri*, emphasizing its potential health benefits. The findings align with those of Gawade et al. (2023), who reported similar benefits in *giloy*-enriched cookies.Giloy (*Tinospora cordifolia*) is known for its medicinal properties, including immune-boosting effects (Sankhala et al., 2012), and its traditional use in managing fever, jaundice, and emaciation (Srivastava, 2020), as well as chronic conditions like diabetes and hepatitis (Saha & Ghosh, 2012). The analysis revealed an increase in moisture, crude fibre, and ash content with rising *giloy* concentration, while protein and fat content decreased in comparison to the control. The rise in fibre and ash enhances the functional value of *panjiri*, particularly for individuals with constipation and lactating mothers. A reduction in fat content is nutritionally advantageous, as excessive fat contributes to rancidity and obesity (Ullah et al., 2003). Although protein content decreased, this may be due to heat-induced denaturation, and the reduction is not nutritionally concerning given the body's limited requirement for protein. Increased moisture improved the palatability of the product, making it more suitable for individuals needing hydration, such as lactating women. Overall, the incorporation of *giloy* enhanced the nutritional profile of *panjiri*, supporting its use as a functional, health-promoting traditional food.

Conclusion- Therefore, it can be concluded that supplemented *panjiri* is definitely better than control *panjiri* and is a healthy option for people suffering with weak immune system, diabetes, urinary track infection; and this type of supplemented food is definitely a boon for lactating mothers as it has sufficient moisture and fibre in their diet and reduces extra fat and extra protein from their meals. *Panjiri* is a good snacking option and can be taken in moderate quantity as per the bodily requirement of the individual consuming it.

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International Journal of Environment, Agriculture and Biotechnology
Vol-10, Issue-3; May-Jun, 2025
Peer-Reviewed International Journal
Journal Home Page Available: https://ijeab.com/
Journal DOI: 10.22161/ijeab

Socioeconomic Importance of Medicinal Plants and Beekeeping in Mountainous Forest Villages of Artvin, Turkey

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Received: 21 May 2025; Received in revised form: 16 Jun 2025; Accepted: 21 Jun 2025; Available online: 26 Jun 2025

Abstract— *This study examines the socio-economic importance of medicinal plants and beekeeping products in mountainous forest villages of Artvin Province, located in northeastern Turkey. Through structured surveys and field observations, the research investigates local knowledge, traditional practices, production methods, and marketing channels in four selected villages: Kayadibi, Camili–Uğur/Çifteköprü, Tütüncüler, and Göktaş. The findings reveal that both medicinal plants and apicultural products significantly contribute to the livelihoods of local communities, with knowledge transmission predominantly occurring within families. Beekeeping activities, often practiced for over a decade, demonstrate the vital role of indigenous knowledge in enhancing productivity and sustaining biodiversity, particularly in designated forest beekeeping zones. The study also highlights local perceptions of climate change impacts, including altered flowering seasons and reduced yields, which pose challenges to resource availability. These insights underscore the importance of integrating traditional ecological knowledge with scientific monitoring to develop adaptive management strategies that support sustainable rural development and biodiversity conservation in mountainous forest regions.*

Keywords— ***Beekeeping, Climate change perception, Medicinal plants, Mountain forest villages, Socioeconomic importance, Sustainable management, Traditional knowledge***

I. INTRODUCTION

Artvin Province, situated in Turkey's northeastern Black Sea region, is distinguished by its rich biodiversity and complex mountainous forest ecosystems, which have long supported the livelihoods of local communities through diverse natural resources (Shackleton, Shanley, & Ndoye, 2011; Shackleton et al., 2015). The integration of traditional ecological knowledge with sustainable resource management is particularly evident in villages such as Kayadibi in Arhavi—home to Turkey's first certified honey forest—and Camili in Borçka, a part of the UNESCO-recognized biosphere reserve (Turner & Berkes, 2006; Pretty & Smith, 2004). These communities rely extensively on non-timber forest products (NTFPs), including medicinal plants and apicultural products, which are crucial for both their economic wellbeing and cultural heritage (Kafle & Awale, 2017; Aydın & Öztürk, 2020).

Despite increasing global recognition of the socioeconomic importance of NTFPs in rural livelihoods, detailed assessments focusing on the combined impact of medicinal plants and beekeeping in Artvin's mountainous areas remain limited (Shackleton et al., 2011; Mertz et al., 2009). Moreover, the vulnerability of these ecosystems and associated livelihoods to climate change has not been sufficiently explored, even though local perceptions and adaptive strategies are essential for resilient forest management (IPCC, 2022; Schroeder & McDermott, 2014).

This study seeks to address these gaps by evaluating the socioeconomic significance of medicinal plants and apicultural products across four selected mountainous forest villages in Artvin: Kayadibi, Camili–Uğur/Çifteköprü, Tütüncüler, and Göktaş. Employing structured surveys and participatory field observations, the research investigates production systems, transmission of traditional knowledge, market access, and community perceptions of climate change. By illuminating these factors, the study aims to inform sustainable ecosystem management and policy development that are sensitive to the unique social-ecological dynamics of forest-dependent communities (Bayrak & Marafa, 2016; Liu et al., 2018)

II. MATERIAL AND METHODS

This study was conducted in four mountainous forest villages of Artvin Province in northeastern Turkey, selected for their richness in medicinal plants and beekeeping products: Kayadibi (population approx. 320), Camili–Uğur/Çifteköprü (approx. 280), Tütüncüler (approx. 310), and Göktaş (approx. 270). The region features a humid, rainy climate influenced by the Black Sea, with rugged terrain and dense natural forests providing diverse habitats for endemic and medicinal plant species. Kayadibi is notable for hosting Turkey's first certified honey forest and a community with extensive apicultural experience. Camili–Uğur/Çifteköprü is near the UNESCO Biosphere Reserve and is recognized for traditional medicinal plant knowledge. Tütüncüler, close to the provincial center, retains mountain village characteristics with developing honey forest beekeeping. Göktaş lies near the Caucasian honeybee gene center and has endemic flora alongside strong traditional beekeeping practices.

Data were collected in 2024 through structured face-to-face interviews with 150 participants, including beekeepers and medicinal plant gatherers, across the four villages. Although these villages have relatively small populations, the sample size represents a significant proportion of local communities, enabling robust analysis of local knowledge, traditional practices, production techniques, and marketing channels. The survey instrument encompassed demographic data, apicultural practices (e.g., hive numbers, honey types, production volumes), medicinal plant collection habits, knowledge transmission pathways, marketing strategies, and local perceptions of climate change effects on production. The questionnaire was developed based on relevant literature and pre-tested for clarity and relevance.

In addition to surveys, structured observation forms were employed during field visits to systematically record data on variables such as village name and date, terrain type (flat, sloped, or forest interior), observed plant species (local names), beekeeping activity types (stationary or migratory), honey forest status and floristic richness, harvesting tools and equipment, and participation levels of women and children. Semi-structured interviews with local cooperative representatives and village administrators provided institutional insights. This mixed-method approach enabled the collection of both quantitative and qualitative data to analyze the ecological and socio-cultural dimensions of rural livelihoods.

Quantitative survey data were entered into SPSS version 25.0 and analyzed using descriptive statistics (frequencies, percentages) to summarize demographic and socioeconomic characteristics. Chi-square tests were used to examine relationships between categorical variables, applied only when the expected frequency assumptions (minimum expected count of 5 per cell) were satisfied. One-way ANOVA was conducted to compare means between groups after verifying normality (Shapiro-Wilk test) and homogeneity of variances (Levene's test). The sample size of 150 ensured adequate statistical power to detect significant patterns and relationships within the communities. Qualitative data from open-ended survey questions and interviews underwent thematic content analysis to interpret local knowledge, perceptions, and challenges.

III. RESULTS

The demographic analysis of the 150 participants revealed generally high literacy and education levels in the Artvin region. Most respondents have at least a high school diploma, with a significant portion holding university degrees (Table 1). The age distribution concentrated between 30 and 60 years, and gender distribution was balanced. The average household size was around 4 to 5 members.

Table 1. Socio-demographic characteristics of the participants

Variable	Category	Frequency (n)	Percentage (%)
Gender	Male	78	52
	Female	72	48
Age (years)	18-30	25	16.7

	31-45	68	45.3
	46-60	45	30
	60+	12	8
Education	Illiterate	5	3.3
	Primary School	25	16.7
	Secondary School	40	26.7
	High School	45	30

More than half of the participants (54.7%) had over 10 years of beekeeping experience (Table 2). Most owned 6 to 10 hives and harvested honey two to three times annually. Chestnut honey was the predominant type produced (66.7%). Marketing was mainly conducted through direct sales (44.7%) and cooperatives (30%).

Table 2. Beekeeping Practices and Production Characteristics of Participants

Variable	Category	Frequency (n)	Percentage(%)
Years of Beekeeping	<5 years	20	13.3
	5-10 years	48	32
	>10 years	82	54.7
Number of Hives	1-5	40	26.7
	6-10	90	60
	>10	20	13.3
Honey Harvests/Year	1 time	18	12
	2 times	75	50
	3 times	45	30
	4+ times	12	8
Honey Type Produced	Chestnut	100	66.7
	Floral	80	53.3
Marketing Channel	Direct Sale	67	44.7
	Cooperative	45	30
	Local Market	30	20
	Other	8	5.3

A Chi-square test showed a significant association between education level and involvement in beekeeping ($\chi^2 = 8.45$, df = 3, p = 0.037). As education level increased, a higher percentage of individuals engaged in beekeeping, suggesting that education may enhance awareness or capability in sustainable livelihood practices (Table 3).

Table 3: Relationship Between Education Level and Beekeeping Involvement

Education Level	Beekeeping (%)	Non-Beekeeping (%)	χ^2 (df)	p-value
Primary	52	48		
Secondary	70	30		
High School	80	20		
University	90	10	8.45 (3)	0.037*

: p < 0.05 indicates a statistically significant difference.

This table presents the relationship between education level and involvement in beekeeping activities. As education level increases, a higher percentage of individuals tend to be engaged in beekeeping. A Chi-square test indicates that this relationship is statistically significant ($\chi^2 = 8.45$, df = 3, p = 0.037). This suggests that higher education may be

associated with increased awareness or capability in sustainable livelihood practices such as beekeeping.

ANOVA results indicated that beekeepers with over 10 years of experience had significantly higher average annual honey yields (22.7 kg) than less experienced beekeepers ($p = 0.004$), emphasizing the importance of knowledge and experience for productivity (Table 4).

Table 4. Beekeeping Experience and Honey Yield

Experience (Years)	Mean Yield (kg)	SD	ANOVA p-value
<5	12.3	3.4	
5-10	18.9	4.1	
>10	22.7	5.2	0.004*

* $p < 0.05$ significant

Respondents collected various medicinal plants, with Origanum vulgare, Hypericum perforatum, Achillea millefolium, Artemisia absinthium, and Mentha spicata being the most common. Collection was mostly carried out by both genders together (55%). The primary use was personal consumption (60%), with 34.7% selling some products.

Table 5. Medicinal Plant Collection and Usage

Variable	Category	Frequency (n)	Percentage (%)
Top Medicinal Plants	Origanum vulgare	110	73.3
	Hypericum perforatum	95	63.3
	Achillea millefolium	80	53.3
	Artemisia absinthium	70	46.7
	Mentha spicata	65	43.3
Collector Gender	Women	45	30
	Men	22	15
	Both	83	55
Usage Purpose	Personal Use	90	60
	Sale	52	34.7
Marketing Method	Market	45	30
	Home Sale	20	13.3
	Internet	10	6.7
	Cooperative	35	23.3

Chi-square test revealed a significant association between gender and involvement in medicinal plant collection ($\chi^2 = 6.12$, $p = 0.013$). Women were more actively involved (75%) compared to men (55%), underscoring women's key role in traditional plant gathering (Table 6).

Table 6. Participation in Medicinal Plant Collection by Gender

Gender	Involved (%)	Not Involved (%)	χ^2 (df)	p-value
Women	75	25	6.12 (1)	0.013*
Men	55	45		

* $p < 0.05$ statistically significant

70% of participants reported changes in yield, and 60% observed changes in flowering periods. Early and delayed blooming were equally reported (30% each), while 50% noted reduced yields (Table 7).

Table 7. Perceptions of Climate Change

Perception	Category	Frequency (n)	Percentage (%)
Change in Yield	Yes	105	70
	No	45	30
Change in Flowering Period	Yes	90	60
	No	60	40
Type of Change	Earlier Blooming	45	30
	Delayed Blooming	45	30
	Reduced Yield	75	50

Chi-square test revealed a significant correlation between education level and perception of climate change ($\chi^2 = 7.89$, df = 3, $p = 0.048$). University graduates reported higher perception rates (85%) compared to primary school graduates (60%), suggesting education enhances environmental awareness and adaptation capacity.

Table 8. Education Level and Climate Change Perception

Education Level	Perceives Change (%)	Does Not Perceive (%)	χ^2 (df)	p-value
Primary	60	40		
Secondary	68	32		
High School	75	25		
University	85	15	7.89 (3)	0.048*

* $p < 0.05$ significant

IV. DISCUSSION

This study investigated the socio-economic role of medicinal plants and beekeeping products in the mountainous forest villages of Artvin province. The findings underscore the intricate relationships between local ecological knowledge, traditional livelihood practices, and environmental dynamics that collectively shape community well-being in this biodiverse region.

Demographic data reveal a relatively high level of educational attainment among the inhabitants of Artvin, which contrasts with trends often observed in rural and remote areas characterized by lower literacy rates (Bayramoğlu, Kaya, & Demir, 2019). This educational advantage likely enhances the community's capacity to adopt and innovate sustainable resource management techniques, fostering participatory approaches and empowering local stakeholders (Çakır & Öztürk, 2021). Moreover, the balanced gender participation observed indicates a progressive model of inclusive forest resource governance, consistent with global calls for gender equity in natural resource management (Bayramoğlu et al., 2019; Colfer et al., 2018).

Long-term involvement in beekeeping, with participants averaging over ten years of experience, correlates positively with higher honey yields and diversification of apicultural products, including regionally distinctive chestnut and meadow honeys. These results align with Kılıç, Kaya, and Yılmaz's (2020) findings, which emphasize the critical role of indigenous knowledge and accumulated expertise in enhancing beekeeping productivity and product quality. Additionally, the existence of designated forest beekeeping zones such as Kayadibi provides an ecosystem-based framework that integrates biodiversity conservation with socio-economic development, exemplifying sustainable forest management practices (Yılmaz, Acar, & Kaplan, 2018; Shackleton et al., 2011).

Medicinal plant harvesting in the studied villages focused on a carefully selected assemblage of species valued for their therapeutic properties, with traditional knowledge primarily transmitted through familial and communal networks. This is congruent with ethnobotanical studies from the Black Sea region, which highlight the cultural significance and economic reliance on endemic and medicinal flora (Güvenç & Duman, 2017; Demirci et al., 2019). Marketing strategies identified include direct local sales and cooperative-based distribution, suggesting initial integration into wider commercial circuits. However, the limited use of digital platforms and social media for product promotion represents an opportunity for enhancing market access and income diversification (Gürbüz & Erdoğmuş, 2020).

Participants consistently reported observable shifts in phenological events, particularly flowering times, alongside fluctuations in yields of both medicinal plants and honey. These perceptions align with empirical climate studies demonstrating altered temperature and precipitation regimes in northeastern Turkey, which have consequential effects on forest ecosystem functions (Öztürk, Demirci, & Şahin, 2022; IPCC, 2022). Such environmental stressors threaten resource availability and sustainability, underscoring the urgency of developing adaptive management strategies that incorporate local observations alongside scientific monitoring to bolster resilience (Turner & Berkes, 2006; Pretty & Smith, 2004).

Overall, this study enriches the understanding of how mountainous forest communities in Artvin navigate socio-economic challenges and environmental uncertainties by leveraging their biological and cultural capital. The integration of traditional ecological knowledge with participatory governance and modern management frameworks can foster sustainable rural development, biodiversity conservation, and climate adaptation in comparable forest-dependent regions worldwide (Bayrak & Marafa, 2016; Liu et al., 2018).

The structured observation forms used during fieldwork provided detailed insights into terrain types, diversity of plant species, and types of beekeeping activities within the study area. Observations revealed a high level of involvement by women and children in beekeeping and plant harvesting activities, indicating strong cooperation and knowledge transfer across gender and age groups within local communities. Furthermore, the floristic richness of honey forests and the diversity of harvesting tools reflect important indicators of sustainable production and economic diversification. These findings support the necessity of integrating traditional ecological knowledge and experiential data gathered through field observations into sustainable rural development and ecosystem management strategies.

V. CONCLUSION

This study highlights the socio-economic importance of beekeeping and the use of medicinal plants in the mountainous forest villages of Artvin, a region rich in biodiversity and traditional ecological knowledge. Based on field surveys and interviews with 150 local residents, it was found that both practices not only contribute to household income but also reinforce community resilience and cultural identity.

The relatively high level of education and traditional knowledge transmission observed in the region supports sustainable resource use and adaptation to environmental change. Participants' awareness of climate-related shifts—such as alterations in flowering periods and honey yield—also reflects their close relationship with nature and their potential role as key actors in local climate adaptation strategies.

The findings suggest that policies supporting local producers, improving market access, and enhancing education on sustainable harvesting practices can further strengthen the livelihoods of these communities. Moreover, the integration of traditional ecological knowledge into conservation and climate adaptation planning would contribute to both biodiversity protection and rural development.

Further research, including longitudinal studies and broader stakeholder engagement, would provide a deeper understanding of how mountainous forest communities can continue to adapt in the face of environmental and economic challenges.

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International Journal of Environment, Agriculture and Biotechnology
Vol-10, Issue-3; May-Jun, 2025
Peer-Reviewed International Journal
Journal Home Page Available: https://ijeab.com/
Journal DOI: 10.22161/ijeab

Contrasting Biodiversity Monitoring Methods in Two NIPAS Sites in Luzon, Philippines: A Mini-Review

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Received: 22 May 2025; Received in revised form: 17 Jun 2025; Accepted: 20 Jun 2025; Available online: 26 Jun 2025

Abstract— *Protected areas under the National Integrated Protected Areas System (NIPAS) in the Philippines serve as critical habitats for biodiversity conservation. This mini-review compares two biodiversity monitoring approaches used in NIPAS-declared areas of Luzon remote sensing in Mt. Pulag National Park and field-based rapid biodiversity assessment in Bataan National Park. The Mt. Pulag study employed Synthetic Aperture Radar (SAR) to detect forest disturbance, while the Bataan study conducted species-level surveys to document biological richness. The review highlights key differences in data type, scale, and application: remote sensing allows for broad-scale, time-series habitat monitoring, while ground-based surveys offer direct ecological insights but are limited by time and area. The review concludes that combining these approaches can create a more effective and adaptive biodiversity monitoring system, aligned with the objectives of the NIPAS framework. An integrated method linking technology, field data, and local participation will better support conservation decision-making in protected areas.*

Keywords— ***biodiversity monitoring, community-based monitoring, field assessment, remote sensing, protected area***

I. INTRODUCTION

Biodiversity monitoring is an essential component of conservation science, providing the empirical basis for understanding ecological dynamics, assessing threats, and guiding the sustainable management of natural resources. In the Philippines a recognized global biodiversity hotspot with over 52,000 documented species, more than half of which are endemic the need for robust monitoring systems is especially urgent due to escalating pressures such as habitat degradation, land-use conversion, and climate change (Aurellado et al., 2021).

To institutionalize the protection and assessment of biologically significant areas, the Philippine government enacted the National Integrated Protected Areas System (NIPAS) Act of 1992 (Republic Act No. 7586), which was subsequently enhanced through the Expanded NIPAS Act of 2018 (Republic Act No. 11038). These legislative frameworks mandate systematic identification, management, and regular evaluation of protected areas, with a strong emphasis on ecological integrity and biodiversity conservation.

The NIPAS framework promotes a decentralized and participatory approach to protected area governance. It mandates the conduct of Biological and Socioeconomic Assessment and Monitoring (BSAM) activities as foundational components of site management (DENR Administrative Order No. 25, 1992). Despite this mandate, implementation challenges persist, including limited technical capacity, methodological inconsistencies, and insufficient integration of local ecological knowledge (Custodio and Molinyawe, 2001). Addressing these systemic constraints is critical for ensuring the long-term effectiveness of biodiversity conservation efforts within the NIPAS system.

Luzon, the largest and most biologically diverse island in the Philippines, hosts several nationally designated protected areas, including Mt. Pulag National Park and Bataan National Park. These sites are ecologically

significant yet face varying levels of anthropogenic pressure and differences in monitoring practice (Llave et al., 2018; Daipan, 2021). This mini-review examines two recent case studies from these NIPAS sites one utilizing remote sensing technology, the other employing field-based rapid biodiversity assessment. Through comparative analysis of these methodologies and their respective outcomes, this review aims to contribute to ongoing discourse on strengthening biodiversity monitoring systems within the NIPAS framework.

II. SUMMARY OF REVIEWED ARTICLES

2.1 Biodiversity Monitoring through Remote Sensing in Mt. Pulag National Park

Daipan (2021) utilized Sentinel-1 Synthetic Aperture Radar (SAR) time series to detect forest disturbances within Mt. Pulag National Park. The study focused on monitoring temporal and spatial changes in forest cover to serve as indicators of human disturbance or ecological stress. By analyzing backscatter changes in radar data, the study identified zones of possible degradation, particularly in areas near human settlements and agricultural encroachment.

The remote sensing approach allowed long-term observation and non-intrusive assessment of land cover changes. However, it did not generate direct species-level data. Instead, the information served as a habitat-based proxy for monitoring ecological pressure, making it useful for tracking trends but limited in documenting actual biodiversity composition.

2.2 Field-Based Rapid Biodiversity Assessment in Bataan National Park

Llave et al. (2018) conducted a rapid biodiversity assessment (RBA) in the buffer zone of Bataan National Park using ground sampling methods such as quadrats, transects, and opportunistic species observations. Their work produced a detailed inventory of flora and fauna, including species richness, endemism, and conservation status.

The study revealed a biologically diverse landscape under threat from human activity, including kaingin farming, poaching, and habitat fragmentation. Unlike the Mt. Pulag study, this assessment produced specific ecological data highlighting key species of conservation interest but lacked the ability to monitor temporal trends or cover large areas.

III. COMPARATIVE ANALYSIS

The two studies offer contrasting strengths and limitations, providing a useful basis for evaluating biodiversity monitoring strategies in protected areas (Table 1).

Table 1. Comparative summary of biodiversity monitoring methods in Luzon NIPAS sites

Feature	Mt. Pulag (Daipan 2021)	Bataan NP (Llave et al. 2018)
Method	Remote sensing (SAR)	Field-based biodiversity survey
Scale	Landscape-scale	Site-specific
Data Type	Habitat condition (proxy)	Species richness, endemism
Strengths	Long-term, broad-scale detection; good for inaccessible areas	Detailed, species-level data; identifies specific threats
Limitations	No direct biodiversity data; cannot identify species	Limited in spatial coverage; one-time data only

Mt. Pulag's approach is excellent for monitoring habitat disturbances over time but does not assess species' diversity directly. In contrast, Bataan's RBA delivers rich biological data but lacks long-term monitoring capacity. Together, they represent two sides of biodiversity assessment habitat trend analysis versus species documentation.

This conceptual framework illustrates the integration of remote sensing, field-based assessments, and local stakeholder participation within the NIPAS monitoring system to inform conservation decisions (Figure 1).

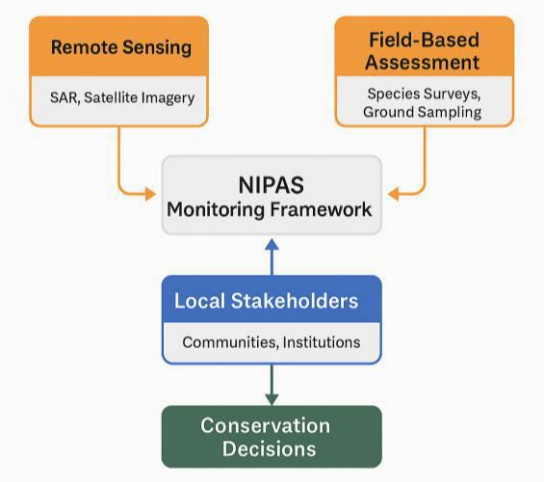

Fig.1. Integrated biodiversity monitoring framework for NIPAS areas in Luzon.

IV. REFLECTIONS AND IMPLICATIONS

The reviewed studies illustrate how biodiversity monitoring in NIPAS areas can benefit from method integration. Remote sensing tools such as SAR enable wide-scale, long-term monitoring of land cover changes, making them ideal for early warning systems and policy enforcement. On the other hand, field-based assessments provide granular data on species presence, richness, and threats crucial for ecological understanding and conservation prioritization.

However, neither approach alone provides a complete picture. Remote sensing lacks biological specificity, while field assessments may be logistically demanding and time limited. To address this gap, an integrated monitoring framework is recommended one that combines remote sensing technology with periodic, standardized field biodiversity assessments. An integrated framework is proposed (Figure 1) to align monitoring efforts with policy goals and management needs. This approach echoes global best practices; the FAO, for instance, emphasizes the use of complementary indicator tools to effectively track biodiversity changes across scales (FAO, 2020; CBD, 2011).

More importantly, effective monitoring should not be viewed solely as a scientific activity but as a participatory governance process. Local communities, indigenous peoples, and academic institutions play a critical role in sustaining monitoring efforts through knowledge sharing, logistical support, and stewardship a model aligning with community-based monitoring principles. This also aligns with the frameworks outlined under NIPAS, which include Biological and Socioeconomic Assessment and Monitoring activities as part of protected area management plans. However, recent reviews of NIPAS implementation highlight persistent gaps such as fragmented monitoring, limited technical capacity, and low integration of community inputs (DENR-BMB, 2018). Addressing these limitations through better protocols, stakeholder engagement, and capacity-building will be essential in enhancing biodiversity conservation outcomes.

V. CONCLUSION

This mini-review highlights the contrasting but complementary roles of remote sensing and field-based approaches in biodiversity monitoring within NIPAS-declared areas in Luzon. The Mt. Pulag study showcases how technology can reveal forest disturbance patterns across time, while the Bataan National Park assessment demonstrates the value of direct species-level data for conservation insight. Each method has distinct advantages and limitations, but together, they offer a more holistic framework for understanding ecological change.

Effective biodiversity monitoring under the NIPAS system should therefore not rely on a single tool but adopt an integrated, adaptive approach. Strengthening this capacity through funding, training, and collaboration will be essential in safeguarding the Philippines' rich but increasingly threatened biodiversity. As biodiversity pressures intensify, investing in science-based, locally grounded monitoring frameworks will be essential to uphold the long-term integrity of the country's protected areas.

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International Journal of Environment, Agriculture and Biotechnology
Vol-10, Issue-3; May-Jun, 2025
Peer-Reviewed International Journal
Journal Home Page Available: https://ijeab.com/
Journal DOI: 10.22161/ijeab

Environmental Attitudes and Visitor Perceptions in Borçka Karagöl Nature Park and Karagöl Sahara National Park

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Received: 19 May 2025; Received in revised form: 15 Jun 2025; Accepted: 21 Jun 2025; Available online: 26 Jun 2025

Abstract— *This study investigates visitor profiles, perceptions, and satisfaction levels at Borçka Karagöl Nature Park and Karagöl Sahara National Park in Turkey. Using on-site surveys and statistical analyses, the research examines socio-demographic characteristics, awareness of conservation efforts, and evaluations of park services. Results indicate that most visitors are young adults with relatively high education and income levels, who show strong awareness and positive attitudes toward environmental protection. However, infrastructure shortcomings and safety concerns, particularly related to traffic congestion and wildlife, affect visitor satisfaction negatively. Socio-demographic factors such as income and education significantly influence conservation awareness and overall experience. The study highlights the need for targeted educational programs, improved infrastructure, and participatory management strategies to enhance both ecological conservation and visitor satisfaction. These findings provide valuable guidance for sustainable tourism planning and protected area management in the region.*

Keywords— ***Protected areas, visitor perceptions, conservation awareness, sustainable tourism, visitor satisfaction, environmental attitudes.***

I. INTRODUCTION

Protected areas play a vital role in conserving biodiversity, maintaining ecosystem services, and providing recreational opportunities for visitors (IUCN, 2020). Consequently, the increasing popularity of nature-based tourism has led to a growing influx of visitors to national parks and protected areas, particularly in regions with rich ecological and cultural heritage. This rise in visitation necessitates a comprehensive understanding of visitor characteristics, motivations, and perceptions to ensure sustainable use and effective management of these valuable areas (Eagles et al., 2002; Buckley, 2012; Larson et al., 2023).

Effective management of protected areas involves not only ecological and infrastructural planning but also a social dimension that accounts for visitor expectations, environmental attitudes, and behaviors (Newsome et al., 2013; Smith & Lee, 2021). Numerous studies emphasize the importance of analyzing visitors' demographic profiles alongside their perceptions of conservation values, recreational satisfaction, and support for protection measures (Weaver & Lawton, 2007; Ballantyne et al., 2008; Zhao et al., 2022). Understanding visitor profiles enables managers to tailor educational and interpretive programs, enhance service quality, and minimize ecological pressures.

Despite growing interest in visitor-focused research globally, studies remain scarce in certain regions such as the Eastern Black Sea Region of Turkey, where mountainous ecosystems, high biodiversity, and rapid tourism development coexist (Çetinkaya & Keskin, 2021; Demir & Aydın, 2023). Borçka Karagöl Nature Park in Artvin is one such protected area that has recently attracted a significant number of domestic tourists. However, empirical data regarding visitors' socio-demographic characteristics, expectations, and perceptions of the park's conservation mission remain limited.

This study aims to explore the socio-demographic characteristics and environmental attitudes of visitors to Borçka Karagöl Nature Park and Karagöl Sahara National Park, and analyze their perceptions of the parks' conservation functions. A questionnaire-based survey was conducted on-site at both locations, and collected data were analyzed using both descriptive and inferential statistical methods. The findings are intended to inform visitor management strategies and contribute to sustainable tourism planning in these protected areas.

The remainder of this paper is organized as follows: Section 2 reviews the relevant literature on visitor studies in protected areas; Section 3 describes the study area and methodology; Section 4 presents and discusses the survey results; and Section 5 concludes with limitations and policy implications.

Understanding visitor behavior and environmental attitudes has become increasingly important for managing protected areas, especially given the global rise in nature-based tourism (Kim et al., 2022; Larson et al., 2023). Visitors to national parks and nature reserves engage in recreational activities but also significantly influence the ecological integrity and social sustainability of these areas through their perceptions, motivations, and behaviors (Torres & Momsen, 2020; Zhao et al., 2022). Consequently, numerous studies highlight the need to link visitor profiles with their conservation awareness and support for protection efforts (Weaver & Lawton, 2007; Ballantyne et al., 2008).

Recent research indicates that socio-demographic factors play a key role in shaping visitor behavior and environmental attitudes (Palomo et al., 2019; Smith & Lee, 2021). Factors such as previous outdoor experiences, personal environmental values, and perceptions of ecosystem services strongly influence how visitors perceive protected areas and their conservation missions (Kim et al., 2022; Çetin & Bilgihan, 2023). These insights assist park managers in designing targeted interpretive programs and behavioral interventions aimed at minimizing ecological impacts.

While visitor perception research in Turkish protected areas is gradually expanding, the geographic scope and depth remain limited, particularly in the biodiverse and rapidly developing Eastern Black Sea Region (Çetinkaya & Keskin, 2021; Demir & Aydın, 2023). This gap underscores the need for empirical studies focused on visitor characteristics, conservation attitudes, and their implications for sustainable management in this region.

Building on existing literature, this study focuses on Borçka Karagöl Nature Park, a heavily visited protected area in northeastern Turkey, to examine visitor perceptions of nature, conservation efforts, and the park's value. The study aims to contribute region-specific, updated data and provide recommendations for visitor management in mountainous protected areas facing growing tourism pressures.

II. MATERIAL AND METHODS

This study was conducted in two protected areas located in Artvin province, northeastern Turkey: **Borçka Karagöl Nature Park** and **Karagöl Sahara National Park**. These areas were selected due to their ecological importance, biodiversity richness, and increasing visitor numbers, providing an appropriate context to analyze visitor interests, perceptions, and attitudes toward conservation and recreational services.

Borçka Karagöl Nature Park is situated within the Karçal Mountains, featuring two lakes formed by landslides at elevations between 1,450 and 1,480 meters above sea level. The park covers approximately 368 hectares and was declared a Natural Park in 2002, recognized for its geological, biological, and landscape values (Artvin Forestry Directorate, 2022). The region exhibits a humid temperate Black Sea climate with an average annual precipitation of 1,268.2 mm and hosts over 900 plant taxa (Çetinkaya & Keskin, 2021).

Karagöl Sahara National Park, declared in 1994, encompasses around 3,250 hectares, with elevations ranging from 1,140 to 2,625 meters. It features a transitional climate between the Eastern Black Sea and Eastern Anatolia zones and includes diverse ecosystems such as the Karagöl lake area and the Sahara plateau (General Directorate of National Parks, 2021). Recent infrastructure developments include accommodation facilities, picnic areas, and hiking trails (Demir & Aydın, 2023).

Data were collected via face-to-face surveys conducted during the peak summer season of 2023, capturing visitor experiences during periods of high visitation. A total of 400 visitors participated, with 200 respondents sampled from each protected area using convenience sampling.

The questionnaire gathered socio-demographic information (age, gender, education, residence) and assessed visitor perceptions of infrastructure, services, conservation efforts, and overall satisfaction. Satisfaction was measured on a 5-point Likert scale (1 = very satisfied to 5 = not satisfied at all). The questionnaire items were grouped into three categories: services provided, conservation perceptions, and visit satisfaction including recommendation likelihood.

The sample size (N=400) was determined based on prior studies in protected area visitor research (Kim et al., 2022; Çetinkaya & Keskin, 2021) and practical considerations related to visitor flow. A power analysis was conducted to ensure the sample size was sufficient to detect medium

effect sizes (Cohen's d = 0.5) with 80% statistical power at a 5% significance level, suitable for planned inferential analyses.

Data were analyzed using descriptive statistics to summarize visitor profiles and satisfaction levels. Inferential analyses, including reliability tests (Cronbach's alpha), exploratory factor analysis, and regression modeling, were performed to identify factors influencing visitor satisfaction and conservation attitudes.

III. RESULTS

Protected areas serve as fundamental components of national and international nature conservation policies (Eagles & McCool, 2002; IUCN, 1994) and are recognized as significant tourist attractions. In Europe, many national parks have been established in regions with centuries of human interaction and have become traditional and renowned tourism destinations (Job, 2008). Protected areas contribute not only to biodiversity conservation and the sustainability of ecosystem services but also offer recreational opportunities (Eagles & McCool, 2002; IUCN, 1994). Borçka Karagöl Natural Park and Karagöl Sahara National Park are key protected areas in the Artvin region, attracting substantial visitor interest.

The socio-demographic characteristics of visitors are summarized in Table 1. Both parks exhibit a similar visitor profile: approximately 62% male and 38% female; the majority (about 60-63%) are aged between 24 and 45; education level is predominantly high school or above (70-75%); and income mainly falls within the 15,000-30,000 TL range (Borçka Karagöl 40%, Karagöl Sahara 46%). These findings align with previous studies indicating that visitors to protected areas tend to be young to middle-aged adults with relatively high educational attainment (Palomo et al., 2019; Kim et al., 2022).

Table 1. Socio-demographic characteristics of the participant

Feature	Borçka Karagöl NP	Karagöl Sahara NP
Gender	62.5% male, 37.5% female	62% male, 38% female
Age (years)	60% aged between 24-45 years	63.5% aged between 24-45 years
Education	70-75% high school or above	70-75% high school or above
Income	40% earn between 15,000-30,000 TL	46% earn between 15,000-30,000 TL

Table 2 presents visitors' awareness of the protected status of the parks and their primary sources of information. A majority of visitors in both parks are aware of their protected area status (Borçka Karagöl 81.5%, Karagöl Sahara 72%). The principal information channels are social networks such as family and friends (29.5%) and media sources (27%). This underscores the importance of social interaction and digital platforms in disseminating conservation knowledge (Weaver & Lawton, 2007).

Table 2. Visitors' Awareness of Protected Area Status and Main Sources of Information

Knowledge Status	Borçka Karagöl NP (%)	Karagöl Sahara NP %
Knowledgeable	81.5	72
Not Knowledgeable	11.5	25
Main Source of Information	Friends/Family 29.5	Media 27

Visitors' evaluations of park services are outlined in Tables 3 and 4, with statistical comparisons summarized in Table 5. Both parks received high satisfaction scores for natural beauty and recreational facilities (mean scores between 1 and 2, where 1 indicates "very satisfied").

Table 3: Visitor Evaluations of Service Areas in Borçka Karagöl Nature Park (%)

Service Area	Strongly Agree %	Agree %	Neutral %	Disagree %	Strongly Disagree %
Natural Beauty	78.5	14.5	3	1	0.5
Recreational Facilities	41	33.5	13.5	4.5	3
Informational Materials	34	31	20	8	4.5
Traffic Congestion (Negative)	28.5	36	13.5	11.5	4.5

However, vehicle traffic density and inadequate transportation infrastructure were perceived negatively, particularly in Karagöl Sahara (mean scores for traffic congestion: Borçka Karagöl 2.58 ± 1.58; Karagöl Sahara 2.79 ± 1.39, p = 0.004). Additionally, the cleanliness of toilets and resting areas as well as accommodation facilities were frequently criticized. These findings highlight the need for improved infrastructure and visitor management to enhance satisfaction in protected areas (Newsome et al., 2013; Eagles & McCool, 2002).

Table 4. Visitor Evaluations of Service Areas in Karagöl Sahara National Park (%)

Service Area	Strongly Agree %	Agree %	Neutral %	Disagree %	Strongly Disagree %
Natural Beauty	59	30.5	6	2.5	0.5
Recreational Facilities	30.5	47	13	7	1.5
Informational Materials	30.5	48.5	8	9	2.5
Traffic Congestion (Negative)	7.5	32	25	30.5	2.5

Regarding conservation efforts most visitors recognize and value protection measures, advocating for increased conservation activities. Approximately 72-81.5% of respondents acknowledge the park's protected status, consistent with prior findings on environmental awareness in protected area visitors (Palomo et al., 2019). Despite this, concerns persist about safety, particularly regarding wildlife threats and insufficient warning signs, suggesting that management should address both ecological and social dimensions of protection (Manfredo, 1992; Mose & Weixlbaumer, 2007).

Table 5. Mean Visitor Ratings and Statistical Comparisons of Service Areas in Borçka Karagöl NP and Karagöl Sahara NP

Service Area	Borçka Karagöl NP (Mean ± SD)	Karagöl Sahara NP (Mean ± SD)	p (t-test)	Cohen's d	Interpretation
Natural Beauty	1.23 ± 0.64	1.51 ± 0.78	0.012*	0.42	Higher satisfaction in Borçka
Recreational Facilities	1.82 ± 1.07	1.99 ± 0.94	0.28	0.16	No significant difference
Informational Materials	2.12 ± 1.16	2.00 ± 1.02	0.43	0.10	No significant difference
Traffic Congestion (Negative)	2.58 ± 1.58	2.79 ± 1.39	0.004*	0.49	More negative in Karagöl Sahara

Visitor attitudes toward protected areas and their satisfaction levels were analyzed based on various socio-demographic variables. Independent samples t-tests and ANOVA analyses revealed that income and education levels significantly influence both visitor satisfaction and conservation awareness. Visitors with higher income levels reported significantly greater satisfaction and awareness regarding the importance of protected areas. Additionally, a positive correlation was found between education level and visitor perception. These findings underscore the importance of considering socio-demographic characteristics in the planning and management of visitor services in protected areas (Kim et al., 2022; Palomo et al., 2019). The relevant statistical analysis results are summarized in the table below.

Table 6. Effects of Income and Education on Visitor Perceptions and Satisfaction in Protected Areas

Analysis Type	Variables	Results / Statistics	Interpretation
Independent Samples t-Test and ANOVA	Visitor Satisfaction and Conservation Attitudes	$p < 0.05$	Significant differences in visitor satisfaction and conservation attitudes
	Income Level and Overall Satisfaction	Higher income visitors gave significantly higher scores	Income level influences satisfaction and conservation awareness
Correlation Analysis	Education Level and Visitor Perception	Pearson $r = 0.45$, $p < 0.01$	Positive correlation between education level and visitor perception

The analysis results in the table indicate that visitors' socio-demographic characteristics play a significant role in shaping their attitudes and satisfaction levels toward protected areas. Notably, visitors with higher income levels tend to give significantly higher scores in both overall satisfaction and conservation awareness. This suggests that individuals with better economic status value the importance of protected areas more and tend to have more positive experiences in these areas.

Furthermore, there is a significant positive correlation between education level and visitor perception. As education level increases, so do conservation awareness and positive perceptions of the protected areas. This supports the idea that more educated individuals are generally more environmentally conscious and have higher awareness regarding the sustainable management of protected areas.

Overall, these findings highlight the importance of considering socio-demographic factors in protected area management. To enhance visitor satisfaction and strengthen conservation awareness, tailored information and education programs targeting different income and education groups would be beneficial.

IV. DISCUSSION

This study provides comprehensive data on visitor profiles, conservation perceptions, and service satisfaction in important protected areas such as Borçka Karagöl Natural Park and Karagöl Sahara National Park, offering critical insights for protected area management and sustainable tourism both locally and within the global literature.

Firstly, the high awareness among visitors about the importance of protected areas and their strong support for conservation efforts align with the increasing social consciousness and environmental awareness documented in the literature (Ballantyne & Packer, 2011; Fernández-Bellon & Kane, 2019). However, the translation of this awareness into effective management policies remains limited due to deficiencies in infrastructure and safety measures. This highlights the challenges of balancing the social, environmental, and economic dimensions within the sustainability paradigm (Berkes, 2004; Reed, 2008).

Traffic congestion and inadequate transportation infrastructure cause habitat degradation and negatively affect visitor experience. These findings indicate that protected area managers need to implement more sensitive planning to balance recreational use and ecological conservation (Monz et al., 2010; Pickering & Hill, 2007). In particular, increased visitor numbers during peak tourism seasons may exceed the carrying capacity and cause habitat deterioration. Consequently, visitor management strategies such as quotas, time restrictions, and development of alternative routes could be employed (Newsome et al., 2013).

Visitors' perceptions of safety and risks related to wildlife highlight the social risks inherent in nature tourism and emphasize the importance of ensuring visitor security (Weaver & Lawton, 2007). Enhancing wildlife warning systems and visitor education programs would not only increase safety but also promote respect for nature.

Requests for preservation and promotion of local culture and traditions reflect the socio-cultural dimension of sustainable ecotourism. In the ecotourism literature, safeguarding cultural heritage and increasing local community participation are seen as critical both for economic benefits and conservation success (Stronza & Gordillo, 2008; Zhao et al., 2021). Involving local communities in these processes enhances the social legitimacy of protected areas and reduces potential conflicts (Berkes, 2004).

The influence of socio-demographic factors on visitor attitudes—especially the direct correlation between education and income levels with conservation awareness—underlines the necessity for targeted education

and awareness programs tailored to visitor profiles (Kim et al., 2022; Palomo et al., 2019). Such programs can effectively increase visitors' respect for nature and conservation behaviors.

Considering the methodological limitations of this study, expanding data collection beyond seasonal periods to include year-round and varying climatic conditions would contribute to understanding the impact of seasonal variations on management strategies (Wilson & Tisdell, 2001). Furthermore, complementing quantitative data with qualitative analyses—such as focus groups and in-depth interviews—would enable a multidimensional and profound understanding of visitor experiences (Liu & Wall, 2006).

Finally, sustainable management of protected areas is achievable only through multi-stakeholder, interdisciplinary, and participatory approaches (Reed, 2008). In this regard, strong collaborations should be established among academic institutions, local governments, civil society, and local communities. Moreover, the widespread use of digital technologies and social media can serve as effective tools for raising conservation awareness and educating visitors (Fernández-Bellon & Kane, 2019).

In summary, visitor management, infrastructure improvements, safety measures, and cultural heritage preservation in Borçka Karagöl and Karagöl Sahara protected areas require strategic planning. Long-term monitoring and participatory management practices in these areas will support both ecological and socio-economic sustainability, ensuring the protection of these areas and the enhancement of their tourism potential.

V. CONCLUSION

In conclusion, the visitor profiles, perceptions, and satisfaction levels in Borçka Karagöl and Karagöl Sahara protected areas provide valuable insights for their sustainable management. While the majority of visitors demonstrate high conservation awareness, infrastructure deficiencies and safety concerns negatively impact overall satisfaction. Furthermore, socio-demographic factors play a significant role in shaping visitor attitudes, highlighting the need for targeted education and awareness programs tailored to different income and education groups. Based on these findings, a multidimensional strategy involving participatory management, infrastructure improvements, cultural heritage preservation, and enhanced visitor safety is essential to ensure the ecological and socio-economic sustainability of these protected areas. Such approaches will not only safeguard natural resources but also improve visitor experiences and contribute to regional development.

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International Journal of Environment, Agriculture and Biotechnology
Vol-10, Issue-3; May-Jun, 2025
Peer-Reviewed International Journal
Journal Home Page Available: https://ijeab.com/
Journal DOI: 10.22161/ijeab

Optimizing the Application Frequency of Trehalose Foliar Fertilizer for Off-Season Tomato (*Solanum lycopersicum* L.) Production in Bacnotan, La Union

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Received: 19 May 2025; Received in revised form: 15 Jun 2025; Accepted: 21 Jun 2025; Available online: 26 Jun 2025

Abstract— *This study evaluated the optimal frequency of trehalose foliar fertilizer application for enhancing the growth, yield, and economic viability of a solanaceous crop cultivated under protected conditions in Bacnotan, La Union. A randomized complete block design was used with four application frequencies: once, twice, thrice, and four times, using a fixed concentration of 2 tablespoons per 16 liters of water. Results showed no significant effects on flowering time, vegetative growth, total yield per area, or pest and disease occurrence. However, a statistically significant increase was observed in the number of fruits per plant, marketable yield, and harvest frequency under thrice application. No further benefit was gained from four applications, indicating a threshold beyond which efficiency declines. These findings support the use of moderate foliar treatment frequency to improve crop productivity while reducing input costs. Further validation under different agroecological conditions is recommended.*

Keywords— ***solanaceous crops, protected cultivation, spray frequency, nutrient efficiency, sustainable farming***

I. INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is one of the most important vegetable crops globally and in the Philippines, both in terms of economic value and dietary contribution. It is widely cultivated for its versatility, nutritional value, and market demand, being a rich source of vitamins A, C, and lycopene an antioxidant associated with health benefits (FAO, 2021). In the Philippines, tomato is commonly grown by smallholder farmers as a cash crop, with its production contributing significantly to rural income and local economies. However, tomato yields are often constrained by biotic and abiotic factors, especially when cultivated under off-season conditions characterized by unpredictable rainfall, higher temperatures, and pest outbreaks (Bureau of Plant Industry, 2020). These stressors can lead to lower fruit set, delayed maturity, and poor fruit quality.

To meet the increasing demand for fresh produce and stabilize supply throughout the year, there is a growing trend toward off-season and protected cultivation, including the use of greenhouses. Yet, off-season production requires improved crop management strategies to mitigate stress-related yield losses. In this context, foliar fertilization has emerged as a supplemental approach to enhance plant resilience and productivity. Unlike soil application, foliar fertilization allows for the direct and rapid uptake of nutrients and plant enhancers through the leaves, especially during critical growth stages or under stress conditions that may limit root uptake (Fernández et al., 2013).

One such plant enhancer is trehalose, a naturally occurring non-reducing disaccharide composed of two glucose molecules. Trehalose functions primarily as an osmoprotectant, stabilizing biological membranes, proteins, and macromolecular structures under stress conditions such as drought, salinity, or oxidative stress

(Garg et al., 2002; Paul et al., 2008). More importantly, trehalose plays a pivotal role in sugar signaling pathways, particularly through its precursor, trehalose-6-phosphate (T6P), which regulates carbon allocation, flowering, and photosynthetic efficiency in plants (Lunn et al., 2014). Exogenous application of trehalose has been shown to improve drought tolerance, enhance pollen viability, delay senescence, and increase biomass and yield in various crops including rice, tomato, wheat, and maize (Iordachescu & Imai, 2008; Kosar et al., 2019).

Despite these well-documented benefits, the optimal frequency of trehalose application particularly via foliar spraying remains underexplored, especially in localized field settings such as off-season tomato production in the Philippines. While some studies indicate that multiple applications may increase yield and stress tolerance, others caution that excessive use may be metabolically costly or even counterproductive, leading to nutrient imbalance or phytotoxicity (Ali & Ashraf, 2011; Schluepmann et al., 2003). Therefore, it is important to assess not only the biological response but also the practical and economic implications of varying application frequencies.

Moreover, research on trehalose has mostly been conducted under laboratory or controlled-environment conditions in temperate regions. There is limited empirical evidence on its performance under tropical lowland greenhouse systems like those used in La Union, Philippines. Given the cost considerations of commercial foliar fertilizers and the limited resources of smallholder farmers, determining the most efficient and profitable frequency of application is essential to promote sustainable adoption.

This study was therefore conducted to evaluate the effect of varying trehalose foliar fertilizer application frequencies on the growth, yield, and economic performance of off-season tomato under protected cultivation. Specifically, the study aimed to (1) determine the frequency of trehalose foliar fertilizer that promotes optimal growth and yield performance, and (2) assess the profitability and practical feasibility of its use under local field conditions. The findings of this research are intended to provide science-based recommendations that can support smallholder farmers, extension practitioners, and agricultural researchers in enhancing off-season tomato productivity through efficient foliar nutrition strategies.

II. MATERIAL AND METHODS

This study, titled *Optimizing the Application Frequency of Trehalose Foliar Fertilizer for Off-Season Tomato (Solanum lycopersicum L.) Production in Bacnotan, La Union*, was conducted to determine the optimal frequency of trehalose foliar fertilizer application for enhancing the growth, yield, and profitability of off-season tomato cultivation under the conditions of DMMMSU-NLUC, Sapilang, Bacnotan, La Union.

2.1 Experimental Site and Design

The experiment was conducted in a 320-square-meter field located in Barangay Casiaman, Bacnotan, La Union. The site was cleared and rotavated using a heavy-duty tractor with two passes to ensure adequate soil preparation. A greenhouse made of bamboo poles and polyethylene plastic sheeting was constructed to provide a semi-controlled growing environment appropriate for off-season production.

The experiment followed a Randomized Complete Block Design (RCBD) with four treatments and three replications. Each replication consisted of five plots per treatment, totaling 60 plots. Each plot measured 1 meter by 5 meters, with a 0.50-meter alley between plots and 1 meter between blocks for easy access. The four treatments were defined by the frequency of trehalose foliar fertilizer application:

T1 – Once application

T2 – Twice application

T3 – Thrice application

T4 – Four times application

Replication (Block)	**Plot 1**	**Plot 2**	**Plot 3**	**Plot 4**
Replication I	**T2**	**T4**	**T1**	**T3**
Replication II	**T3**	**T2**	**T4**	**T1**
Replication III	**T1**	**T3**	**T2**	**T4**

2.2 Sowing and Transplanting

Tomato seeds (*Diamante Max* variety) were sown singly in individual cells of plastic seedling trays and lightly covered with soil. Watering was done immediately after sowing to provide sufficient moisture for germination. Seedlings were maintained under nursery conditions for approximately one month, after which they were transplanted into the field.

Planting holes were prepared in a double alternate row system, with 40 cm spacing between both hills and rows. Transplanting was performed in the late afternoon to minimize transplant shock, followed by immediate irrigation to support seedling establishment.

2.3 Fertilizer and Treatment Application

Prior to transplanting, each planting hole received 10 grams of processed vermicompost as basal organic fertilizer. At three weeks after transplanting, 5 grams of

complete inorganic fertilizer (14-14-14) were applied to each plant. This was done by creating a 9 cm-deep hole near the base of each plant, depositing the fertilizer, and immediately covering it with soil to minimize nutrient loss.

The trehalose foliar fertilizer was applied starting one month after transplanting, following the assigned treatment frequencies. A fixed concentration of 2 tablespoons of trehalose per 16 liters of water was used across all treatments. Applications were conducted using a standard knapsack sprayer until the foliage was thoroughly wetted.

2.4 Cultural Practices

Standard cultural management practices for tomato cultivation were observed throughout the cropping period, including regular watering, manual weeding, and pest and disease control (Cardenas and Siladan, 2010). Watering was done early in the morning using a garden hose with a nozzle for uniform distribution. Weeding was carried out manually around each plant and across the experimental area to prevent competition for nutrients and sunlight. Pest and disease monitoring was performed through regular visual inspection, and appropriate control measures were applied when necessary.

2.5 Harvesting and Sampling

Harvesting was done manually once fruits reached physiological maturity. Marketable and non-marketable fruits were separated at harvest and placed in distinct containers. From each treatment plot, 10 sample plants were randomly selected and used as the basis for data collection.

2.6 Parameters Measured

The following growth and yield parameters were recorded:

Days from Transplanting to Flowering. Number of days from transplanting to the first visible flower. *Days from Transplanting to First Harvest.* Number of days from transplanting to the first mature fruit harvest. *Days from Fruit Setting to First Harvest.* Number of days from visible fruit setting to first harvest. *Plant Height at Flowering (cm).* Measured from the base to the tip of the longest leaf using a foot rule on 10 sample plants per plot. *Average Number of Leaves at First Harvest.* Counted from 10 sample plants and averaged. *Leaf Area at Flowering (cm²).* Measured using a handheld Leaf Area Index (LAI) meter on 10 sample plants per plot. *Flower to Fruit Ratio (%).* Calculated as (Number of Fruits / Number of Flowers) × 100. *Average Fruit Weight per Plant (kg).* Determined by weighing fruits per sample plant and computing the mean. *Average Number of Fruits per Plant.* Counted and averaged per sample plant. *Marketable Yield (kg/plot).* Weight of harvested fruits per plot free from deformities or damage.

Non-Marketable Yield (kg/plot). Weight of fruits per plot that were damaged, deformed, or substandard. *Number of Harvests.* Total count of harvest events per treatment over the fruiting period.

Total yield (kg/plot). This was the total weight of marketable and non-marketable fruits per treatment in each plot.

Computed yield per hectare (ton/ha). This was determined by the marketable yield per plot. *Occurrence of Pests and Diseases.* Assessed through regular visual observation.

III. RESULTS AND DISCUSSION

3.1 Days from Transplanting to Flowering

As shown in Table 1, the frequency of trehalose foliar fertilizer application did not result in a statistically significant difference in the number of days from transplanting to flowering. Although the thrice and four-times application treatments showed slightly earlier flowering compared to the once and twice application treatments, these variations were not significant. The coefficient of variation (CV) of 5.85% reflects acceptable experimental consistency. These findings indicate that, under the conditions of the study, increasing the frequency of trehalose application did not produce a substantial effect on the onset of flowering. In this context, lower application frequencies, such as a single application, may be considered sufficient in terms of flowering response, particularly when viewed from the perspective of input efficiency and resource management.

3.2 Days from Transplanting to First Harvest

As shown in Table 2, the frequency of trehalose foliar fertilizer application did not result in a statistically significant difference in the number of days from transplanting to first harvest. Although the thrice application treatment recorded the earliest harvest at 81.63 days and the twice application the latest at 86.30 days, these numerical differences were not significant. The relatively low coefficient of variation (CV) of 3.52% indicates good consistency across treatments. These results suggest that increasing the frequency of application did not meaningfully influence the timing of fruit maturity. Therefore, a single application may be adequate for achieving a comparable harvest timeline, offering practical benefits in terms of input savings and operational efficiency without compromising crop development.

3.3 Days from Fruit Setting to First Harvest

As shown in Table 3, the frequency of trehalose foliar fertilizer application did not result in a statistically significant difference in the number of days from fruit setting to first harvest. Although the thrice application treatment recorded the shortest interval (41.27 days) and the twice application the longest (43.23 days), the variation among treatments was not significant. The coefficient of variation (CV) of 6.92% indicates moderate experimental consistency. These results suggest that increasing the frequency of trehalose application did not have a substantial influence on the rate of fruit maturation once fruit setting had occurred. Accordingly, a single application may be sufficient to maintain a similar harvest interval, offering a practical advantage in reducing input use without affecting harvest timing at this stage of development.

3.4 Plant Height at Flowering (cm)

As shown in Table 4, the frequency of trehalose foliar fertilizer application did not result in a statistically significant difference in plant height at flowering. Although the tallest plants were observed in the four-times application treatment (64.47 cm), followed closely by the thrice application (62.37 cm), and the shortest in the twice application (54.63 cm), the observed differences were not statistically significant. The coefficient of variation (CV) of 15.70% indicates relatively high variability among treatments. These results suggest that increasing the frequency of trehalose application had no substantial effect on vegetative height at flowering. Therefore, a single application may be adequate to support comparable plant growth, providing a practical benefit in terms of reduced input use and labor without compromising early vegetative development.

3.5 Average Number of Leaves at First Harvest

As shown in Table 5, the frequency of trehalose foliar fertilizer application did not result in a statistically significant difference in the average number of leaves at first harvest. While the highest number of leaves was recorded in the four-times application treatment (25.03), and the lowest in the once application treatment (19.47), these differences were not statistically significant. The coefficient of variation (CV) of 13.26% indicates moderate variability among treatments. These findings suggest that increasing the frequency of trehalose application did not lead to a substantial increase in foliage development by the time of first harvest. Hence, a single application may still support acceptable vegetative growth, offering efficiency in input use without significantly affecting leaf development.

3.6 Leaf Area at Flowering

As shown in Table 6, the frequency of trehalose foliar fertilizer application did not result in a statistically significant difference in leaf area index (LAI) at the flowering stage. The highest LAI was recorded in the once application treatment (183.22), while the lowest was observed in the four-times application treatment (160.25). Despite these numerical differences, the variation among treatments was not statistically significant. The coefficient of variation (CV) of 16.74% indicates a relatively high degree of variability. These findings suggest that increased frequency of trehalose application did not enhance leaf area development during flowering. In fact, a single application yielded the highest mean LAI, implying that minimal application may already be sufficient to support favorable leaf expansion, thus offering potential savings in labor and input costs.

3.7 Flower to Fruit Ratio

As shown in Table 7, the frequency of trehalose foliar fertilizer application did not result in a statistically significant difference in flower to fruit ratio. The highest ratio was observed in the twice application treatment (55.44%), while the lowest was in the once application (47.40%). Although the twice application showed a numerically higher conversion rate, the differences among treatments were not statistically significant. The coefficient variation (CV) of 18.32% indicates relatively high variability across replications. These results suggest that increasing the frequency of trehalose application did not consistently enhance fruit set efficiency. Therefore, a lower frequency of application, such as a single or twice application, may already support acceptable reproductive performance while maintaining input efficiency.

3.8 Average Fruit Weight per Plant and Average Number of Fruits per Plant

As shown in Table 8, the frequency of trehalose foliar fertilizer application did not result in a statistically significant difference in the average weight of fruits per plant. Although the highest average weight (1.67 kg) was recorded in both the twice and thrice application treatments, and the lowest in the once application (1.46 kg), the variation was not statistically significant. The coefficient of variation (CV) of 8.11% indicates moderate variability. These results suggest that fruit weight was relatively stable across different application frequencies, implying that even minimal application may be sufficient to maintain acceptable fruit mass.

In contrast, a statistically significant difference was observed in the average number of fruits per plant. The four-times application treatment produced the highest number of fruits (45.77), significantly greater than the

once application (38.34), which recorded the lowest. The CV of 3.62% reflects high consistency in this parameter. These results indicate that increased frequency of trehalose application may enhance fruit set. Trehalose plays a key role in stress signaling and carbohydrate regulation, which can improve reproductive development under suboptimal conditions (Schluepmann et al., 2003). Furthermore, studies have shown that exogenous trehalose application can enhance pollen viability and fertilization efficiency, resulting in greater fruit production (Lordachescu & Imai, 2008). Therefore, while frequent application may increase fruit count, economic viability should also be considered when determining the optimal application frequency.

3.9 Marketable Yield (kg/plot) and Non-Marketable Yield (kg/plot).

As shown in Table 9, a statistically significant difference was observed in the weight of marketable yield per plot across different frequencies of trehalose application. The highest marketable yields were recorded in the thrice (38.89 kg) and twice (38.87 kg) application treatments, both significantly higher than the yields from the once (33.44 kg) and four-times (35.01 kg) applications. The coefficient of variation (CV) of 5.25% indicates high consistency. These results suggest that moderate frequencies of trehalose application may optimize marketable fruit production, possibly due to improved physiological processes such as osmoprotection, stress tolerance, and sugar regulation during critical growth stages. Trehalose has been shown to enhance photosynthetic activity and resource allocation, which are closely linked to increased fruit set and quality (Paul et al., 2008; Garg et al., 2002). Excessive application, as seen in the four-times treatment, may not yield further benefits and could potentially disrupt the plant's metabolic balance.

In contrast, the weight of non-marketable yield did not differ significantly among treatments. While the thrice application recorded the lowest non-marketable yield (1.11 kg), and the once application the highest (1.60 kg), the differences were not statistically significant, as indicated by a high CV of 74.55%. This suggests that trehalose frequency had limited influence on fruit rejection rates, which may instead be attributed to uncontrolled environmental factors or incidental pest damage during the cropping cycle.

3.10 Number of Harvests

As shown in Table 10, the frequency of trehalose foliar fertilizer application had a statistically significant effect on the number of harvests per plant. The thrice (10.30) and four-times (10.10) application treatments resulted in significantly more harvests compared to the once (8.63) and twice (8.60) application treatments. The coefficient of variation (CV) of 4.92% indicates a high level of consistency in the data. These findings suggest that more frequent application of trehalose may extend the fruiting period, enabling additional harvest events.

This increase in harvest frequency may be attributed to trehalose's role in delaying senescence and supporting prolonged physiological activity in plants. Trehalose treatments have been shown to delay floral and leaf senescence in ornamental species by maintaining membrane integrity and cellular function. Additionally, trehalose metabolism, particularly through its intermediate trehalose-6-phosphate (T6P), is implicated in integrating sugar signals that regulate growth and prolong plant developmental processes (Lunn et al., 2014). By delaying the onset of senescence and sustaining productive tissue, plants receiving three to four applications may sustain fruit production over a longer period, resulting in more harvests. Moreover, exogenous trehalose application has also been associated with extended chlorophyll retention and enhanced source–sink efficiency in several fruit crops, contributing to prolonged yield periods (Joshi et al., 2020). However, as with other parameters, the economic viability of multiple applications should be considered in relation to the added input costs.

3.11 Total yield per plot and computed yield in tons per hectare

As shown in Table 11, the frequency of trehalose foliar fertilizer application did not result in a statistically significant difference in total yield per plot or computed yield per hectare. The highest total yield (16.65 kg per 5 m^2) and computed yield (31.05 tons/ha) were recorded in the thrice application treatment, followed by the four-times application (29.13 tons/ha), and the lowest in the once application (26.33 tons/ha). Despite these numerical differences, the variation among treatments was not statistically significant. The coefficients of variation (CV) were 8.97% and 7.96% for total yield and computed yield, respectively, indicating acceptable experimental precision. These findings suggest that increasing the frequency of trehalose application did not significantly enhance yield performance. From a production standpoint, lower application frequencies, particularly a single or twice application may already support comparable yield levels, offering potential advantages in terms of reduced cost and labor without sacrificing productivity.

3.12 Occurrence of Pests and Diseases

As shown in Table 12, the frequency of trehalose foliar fertilizer application did not result in a statistically significant difference in the incidence of whiteflies and tomato leaf curl. The lowest mean incidence of whiteflies was observed in the four-times application treatment

(2.00), while the highest was recorded in the once application (3.00). For tomato leaf curl, the lowest incidence was in the twice application (1.00), with other treatments recording similar values (1.33). Despite these variations, the differences among treatments were not statistically significant. The coefficients of variation were 18.86% for whiteflies and 46.19% for tomato leaf curl, indicating high variability, particularly for the latter. These results suggest that increasing the frequency of trehalose application did not effectively reduce pest or disease incidence. Therefore, while trehalose may support plant growth, its use alone may not provide adequate protection against common pests and diseases, and integrated crop protection strategies remain necessary.

IV. TABLES

Table.1: Number of days from transplanting to flowering

Frequency of Application	Mean (Days)
Once Application	39.00
Twice Application	39.43
Thrice Application	36.67
Four times Application	36.80
CV (%)	5.85

Table.2: Number of days from transplanting to first harvest

Frequency of Application	Mean (Days)
Once Application	84.77
Twice Application	86.30
Thrice Application	81.63
Four times Application	83.20
CV (%)	3.52

Table.3: Number of days from fruit setting to first harvest

Frequency of Application	Mean (Days)
Once Application	41.47
Twice Application	43.23
Thrice Application	41.27
Four times Application	43.10
CV (%)	6.92

Table.4: Plant height at flowering (cm)

Frequency of Application	Mean (Days)
Once Application	57.23
Twice Application	54.63
Thrice Application	62.37
Four times Application	64.47
CV (%)	15.70

Table.5: Average number of leaves at first harvest

Frequency of Application	Mean (number)
Once Application	19.47
Twice Application	23.73
Thrice Application	23.20
Four times Application	25.03
CV (%)	13.26

Table.6: Leaf area at flowering (LAI)

Frequency of Application	Leaf Area Index
Once Application	183.22
Twice Application	164.34
Thrice Application	170.99
Four times Application	160.25
CV (%)	16.74

Table.7: Flower to fruit ratio (%)

Frequency of Application	Mean (%)
Once Application	47.40
Twice Application	55.44
Thrice Application	49.86
Four times Application	50.25
CV (%)	18.32

Table.8: Average weight (kg) and number of fruits per plant

Frequency of Application	Average weight of fruit/plant	Average no. of fruits/plant
Once Application	1.46	38.34[c]
Twice Application	1.67	41.67[b]

Thrice Application	1.67	42.43[b]
Four times Application	1.58	45.77[a]
CV (%)	8.11	3.62

Note: Means with the same letter are not significantly different.

Table.9: Weight of marketable and non-marketable yield per plot (kg)

Frequency of Application	Weight of marketable yield (kg/plot)	Weight of non-marketable yield (kg/plot)
Once Application	33.44[b]	1.60
Twice Application	38.87[a]	1.29
Thrice Application	38.89[a]	1.11
Four times Application	35.01[b]	1.17
CV (%)	5.25	74.55

Note: Means with the same letter are not significantly different.

Table.10: Number of harvestings per plant

Frequency of Application	Mean (number)
Once Application	8.63[b]
Twice Application	8.60[b]
Thrice Application	10.30[a]
Four times Application	10.10[a]
CV (%)	4.92

Note: Means with the same letter are not significantly different.

Table.11: Total yield per plot and computed yield in tons per hectare

Frequency of Application	Total yield (kg/5m^2)	Computed yield (tons/ha)
Once Application	14.77	26.33
Twice Application	15.87	28.70
Thrice Application	16.65	31.05
Four times Application	15.73	29.13
CV (%)	8.97	7.96

Table.12: Incidence of insect pests and diseases

Frequency of Application	White flies	Tomato leaf curl
Once Application	3.00	1.33
Twice Application	2.67	1.00
Thrice Application	2.33	1.33
Four times Application	2.00	1.33
CV (%)	18.86	46.19

V. CONCLUSION

This study demonstrated that the frequency of trehalose foliar fertilizer application significantly influences select reproductive and yield traits of off-season tomato (*Solanum lycopersicum* L.) under greenhouse conditions in Bacnotan, La Union. While most growth parameters including days to flowering and harvest, plant height, leaf area, and total yield were not statistically affected by varying application frequencies, key yield-related indicators showed meaningful responses.

Specifically, applying trehalose three times resulted in the highest marketable yield, fruit number per plant, and harvest frequency, outperforming both lower and higher frequencies. Although four applications also increased fruit count and harvests, they did not significantly exceed the results of thrice application, suggesting diminishing returns at higher input levels.

From both agronomic and economic perspectives, thrice application of trehalose strikes the most effective balance between productivity and resource efficiency. Meanwhile, once or twice application still supported comparable growth and acceptable yields, indicating practical benefits for cost-conscious farmers. These findings underscore the potential of trehalose as a foliar input in improving off-season tomato production, provided it is applied judiciously.

Further field trials across different agroecological zones and production systems are recommended to confirm these results and refine application strategies for broader adoption.

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International Journal of Environment, Agriculture and Biotechnology
Vol-10, Issue-3; May-Jun, 2025
Peer-Reviewed International Journal
Journal Home Page Available: https://ijeab.com/
Journal DOI: 10.22161/ijeab

Antagonistic potential of phylloplane *Bacillus subtilis* PBs4 isolate against grain mold fungi of sorghum in India

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Received: 23 May 2025; Received in revised form: 21 Jun 2025; Accepted: 25 Jun 2025; Available online: 29 Jun 2025

Abstract— *In India grain mold disease incited by a number of saprophytic fungi is a major disease of sorghum that results into qualitative as well as quantitative loss of produce due to infection of maturing grains. Use of chemical fungicides on maturing grains may impose serious health hazards, therefore, use of antagonistic microbes may provide an effective alternative to contain this serious problem. In vitro assessment of Bacillus subtilis isolates collected from phylloplane of sorghum, rice, cotton, soybean, pigeonpea and chilli was done by dual culture method for their potential antagonism against major grain mold fungal pathogens of sorghum i.e. Fusarium moniliforme, Alternaria alternata, Curvularia lunata and Phoma sorghina. Amongst the six Bacillus isolates, maximum inhibition of mycelial growth was registered by PBs4 against F. moniliforme (75.99%), A. alternata (81.86%), C. lunata (78.09%) and P. sorghina (67.68%) followed by PBs3 and PBs2 indicating maximum antagonistic potential of Bacillus subtilis PBs4 against sorghum grain mold causing fungi.*

Keywords— ***Alternaria alternata, Bacillus subtilis, Curvularia lunata, Fusarium moniliforme, Phoma sorghina, Grain Mold***

I. INTRODUCTION

Bacillus species have been widely recruited in biocontrol of plant diseases for more than 50 years because of their well-developed secretary system that produce structurally diverse secondary metabolites displaying a wide spectrum of antagonistic activity (Araujo *et al*., 2005; Awais *et al.*, 2007; Liu *et al*. 2007). Phylloplane isolates of *Bacillus subtilis* are particularly useful as biocontrol agents as they increase yields and stimulate plant growth and are also responsible for increasing total biomass production, leaf area, chlorophyll concentration and nitrate reductase activity. *Bacillus subtilis* has been reported as the most promising biocontrol agent under a variety of environmental conditions against various plant pathogens (Chen *et al*. 2008). As a largest source of wide array of bioactive natural compounds *Bacillus* species are reported to be used as an antifungal antagonist (Abd El-Ghafar, 2008; Shrivastava *et al*., 2013; Narasimhan & Shivakumar, 2014). *Bacillus subtilis* showed resistance only to penicillin, amoxicillin and ampicillin antibiotics. The antibiotics obtained from the culture of certain members of the *B. subtilis* family produce a wide variety of antimicrobial substances like chitinase, sublancin, subtilin, subtilosin A, and TasA those are ribosomal antibiotics and others, like bacillaene, bacilysin, chlorotetain, difficidin, mycobacillin, rhizocticins and lipopeptides including fengycins, iturins and surfactins are produced under the facilitation of non-ribosomal peptide synthetases and polyketide syntheses (Araujo *et al*., 2005; Awais *et al.*, 2007; Akond *et al*. 2016, Zhen *et al*. 2023). Several members of the genus *Bacillus*, including *Brevibacillus* and *Paenibacillus* spp. are capable of producing more than 70 different antibiotics (Araujo *et al*., 2005; Awais *et al.*, 2007). Many airborne, seed-borne and soil borne diseases of rice, wheat, sugarcane, jute, groundnut, cotton, rubber, soybean, tobacco and vegetables etc. are reported to be

controlled by *B. subtilis* (Araujo *et al.*, 2005; Yogo *et al*., 2011; Xiao *et al*., 2014; Smitha *et al.*, 2017). Akond *et al.* (2016) reported that the members of *Bacillus* genus can colonize the root and leaf system of plants and compete thereby suppressing the growth of plant pathogens. Phylloplane microorganisms like *B. subtilis* are receiving considerable attention as potential prophylactic bioagents to protect the plants against foliar fungal pathogens. Due to its capacity and potential to colonize on phylloplane the *B. subtilis* acts as a barrier restricting invasion of pathogens. As documented by Hoch *et al.* (1993) amongst bacterial biocontrol agents, *Bacillus* genus possess a large genetic biodiversity encompassing diverse climatic conditions ranging from soil to sea water and even the extreme environmental situations of hot springs. Therefore, this bacterium retains several valuable traits and is one of the major sources of potential biopesticides of microbial origin (Ongena and Jacques 2008). US Food and Drug Administration (USFDA) has granted the "Generally Regarded as Safe" (GRAS) status to *B. subtilis* which is thus recognized as non-pathogenic (Harwood and Wipat 1996) that is essential for its application as a biopesticide. Further, *Bacilli* are known to produce spores (Piggot and Hilbert 2004) those are extremely resistant dormant forms capable of withstanding unfavourable pH, lack of nutrients, lack of water, high temperatures, etc. Spores are produced by the bacteria under unfavourable environmental conditions to help them survive through adversities.This study was aimed to compare six isolates of *B. subtilis* obtained from phylloplane of different field crops of Central India, for their ability to suppress grain mold fungal pathogens of sorghum through the production of cyclic lipopeptides, hydrolytic enzymes and siderophores.

II. METHOD

Isolation of grain mold causing fungi and pathogenicity test

Diseased sorghum ear heads were collected from different districts of Vidarbha region of Maharashtra, India for isolation of grain mold causing fungi,. Four species of fungi i.e. *Fusarium moniliforme, Alternaria alternata, Cuvrularia lunata* and *Phoma sorghina* were isolated on Potato Dextrose Agar (PDA) medium by tissue isolation technique. Pathogenicity tests were performed for collected fungal cultures. For further study, one isolate of each specie with proven pathogenicity was maintained as axenic culture on PDA media (Petkar, 2021).

Isolation of *B. subtilis* from phylloplane

By employing serial dilution technique 6 isolates of *B. subtilis* were collected from phylloplane of healthy leaves of six field crops i.e. sorghum, rice, cotton, soybean, pegionpea and chilli on Nutrient Agar (NA) medium. For preparing water blank test tubes with 9 ml distilled water were sterilized in an autoclave. To remove dust particles and loosely adhering unassociated microbes, after gentle rinsing in the sterilized distilled water for a few minutes the collected leaf samples were placed in 100 ml sterilized distilled water and shaken vigorously for 30 min. Serial dilutions were prepared from 10^{-1} to 10^{-10} dilutions. One millilitre sample from 10^{-7} dilution was transferred on NA media in Petri-plates. Inoculated Petri-plates were incubated for 48 hours at room temperature. One representative growth of visibly distinguishable bacterial colony was transferred to a fresh NA media plate to develop the pure culture and designated as PBs1 to PBs6, respectively, corresponding to the field crops mentioned earlier (Petkar, 2021).

Biochemical properties of phylloplane *B. subtilis* isolates

Biochemical tests viz., acid production from carbohydrates, catalase test, gas production from carbohydrates, gelatin liquefaction, Gram's reaction, H_2S Production, KOH test, starch hydrolysis, methyl red test, etc. were performed for biochemical confirmation of *B. subtilis* isolates. All the isolates of *B. subtilis* were further evaluated for plant growth promotion properties viz., IAA production and phosphate solubilization etc.

Gram's reaction

Bacillus subtilis was identified by Gram's staining and by studying the morphological characters of the bacteria (Jha *et al.* 2016 & Kapali *et al.* 2016). Gram's staining was performed using crystal violet as main stain (30 seconds), potassium iodide/ Lugol's iodine solution (30 seconds) as fixer, 95% alcohol as decolourizer and saffranin (10 seconds) as counterstain. After staining drop of cedar wood oil was placed on the slide and smear was examined under the oil immersion lense.

Potassium hydroxide (KOH) solubility test

Two drops of KOH were placed on a glass slide. A colony of *B. subtilis* isolate culture was picked up from the medium with the help of inoculation needle and mixed with KOH for 10 seconds and needle was raised for 0.5 to 2 cm to form thread which was treated as positive test (Petkar, 2021).

Starch hydrolysis

Starch is a complex carbohydrate (polysaccharide) composed of two constituents; amylose, a straight chain polymer of 200-300 glucose units and amylopectin, a larger branched polymer with phosphate groups. The positive test indicates by the presence of amylase enzyme,

an exoenzyme that hydrolyses (cleaves) starch, into maltose (disaccharide) and some monosaccharides such as glucose. For this test *B. subtilis* isolate was inoculated on starch agar plates and incubated for 7 days. After incubation, the plates were flooded with Lugol's iodine solution. Appearance of clear zone indicated complete hydrolysis of starch and reddish zone indicated partial hydrolyses of starch to dextrin. (Xiao Hua Zhang *et al*. 2014)

Catalase test

During aerobic respiration microorganisms (MO's) produce hydrogen peroxide (H_2O_2) which is lethal to themselves. In some MO's catalase enzyme is present that breaks down H_2O_2 to water (H_2O) and oxygen (O_2) and helps them to survive under aerobic conditions. Catalase test was performed by adding H_2O_2 to Trypticase Soy Agar slant culture of *B. subtilis* isolate. Release of free oxygen gas (O_2) bubbles indicated positive catalase test **(**Mandla *et al*. 2017**).**

Gelatin liquefaction

Gelatin is a protein produced by hydrolysis of collagen which is a major component of tendons and connective tissue in humans and other animals. Bacterium capable of producing proteolytic exoenzyme gelatinase, hydrolyzes gelatin to amino acids resulting into liquefaction. To conduct this test *B. subtilis* isolates were inoculated to stab of a nutrient gelatin (i.e. Nutrient broth + 1.5% gelatin) and incubated for 7 days and observed for liquefaction. Uninoculated tubes were compared as control. Liquified tubes showed presence of gelatinase activity i.e. positive test for gelatin hydrolysis and tubes that remained solid indicated negative test for gelatin hydrolysis (Avsar *et al.* 2017).

Hydrogen Sulphide (H_2S) production

Production and liberation of H_2S gas results due to the activity of bacterium on sulphur containing amino acids. H_2S gas reacts with lead acetate to turn it black. So, lead acetate paper was prepared by moistening the filter paper in saturated solution of lead acetate to test the H_2S production. In the tubes containing peptone water (i.e.peptone 1%, cystine 0.01%, NaCl 0.5%) inoculated with *B. subtilis* isolate, the lead acetate paper was kept holding by the plugs above the culture, without touching the media. The tubes were incubated for 3 days. Turning of lead acetate paper strips black indicated positive test for H_2S production (Abbo *et al.* 2014).

Indole production

Tryptophan is an essential amino acid that is oxidised by some bacteria capable of producing tryptophanase enzyme resulting into formation of indole, pyruvic acid and ammonia. The indole test was performed by inoculating bacterium into 1% tryptone broth (i.e. 10 gm of tryptone in one litre of distilled water), and production of indole during the reaction was detected by adding Kovac's reagent (i.e. P-di-methylamino benzaladehyde 50g, amyl alcohol 750ml, HCl 250ml) that produces a cherry-red reagent layer. In this procedure medium was distributed in test tubes and autoclaved. *B. subtilis* isolate was inoculated and incubated for 48hrs and Kovac's reagent (1ml) was added in incubated test tubes. The tubes were allowed to stand to permit the reagent to surface on top. Development of a cherry (deep) red colour on the top layer of the tube indicated positive test for indole production. Absence of red colouration indicated negative test for indole production (Zhang *et al*. 2008).

Acid and Gas production from carbohydrates

Dextrose broth (Nutrient broth + 0.5% dextrose) was prepared with the test reagent (20 ml broth + 0.2 ml Bromo-Cresol purple). In each test tube 10 ml dextrose broth was filled and one durham tube was placed in inverted position. After sterilization of test tube it was inoculated with *B. subtilis* isolates and incubated for 3 days at room temperature. When colour of indicator changed from blue to yellow it indicated formation of acid and gas by it's accumulation in Durham tube that was a positive test whereas in uninoculated control colour of indicator remained blue (Baeman *et al.* 2011).

Casein Hydrolysis

Many bacteria produce enzymes that hydrolyze protein. To perform this test *B. subtilis* isolate was inoculated on skim milk agar (Nutrient Agar + 2% raw skim milk) plates and incubated for 3 days. Colonies of organism which digest casein appeared surrounded by clear zones indicating a positive test. Areas in which the casein was attacked remained slightly opaque, whereas in negative test no zone formation was observed (Tariq *et al*. 2016).

Phosphate solubilization

To perform this test *B. subtilis* isolate was spot inoculated on Pikovaskaya's media. After inoculation plates were incubated for 4-5 days at 28 ± 1^0C temperature. Solubilization of phosphate was indicated by the formation of a clear inhibition zone arround the colony indicating positive test. No zone formation was observed in uninoculated control (Jadhav *et al*. 2014).

Methyl red (MR) Test

MR test was performed to check the cleavage of glucose which is commonly used in the differentiation of organisms. To perform the test Glucose Phosphate Broth media (Glucose 0.5%, K_2HPO_4 0.5%, Peptone 0.5%,

distilled water 1litre) was filled in the test tubes and sterilized. After inoculation with *B. subtilis* isolate tubes incubated for 7 days at 27±2^{0}C temperature. Five drops of the methyl red indicator (0.1g Methyl red dissolved in 300ml of 95% ethanol and made up to 500ml with distilled water) were added to 5ml of culture. Production of Red color indicated a positive test, whereas, yellow coloration was recorded as negative test (Singh *et al*. 2017).

***In vitro* efficacy of *B. subtilis* isolates**

Collected phylloplane *B. subtilis* isolates were tested for their antagonistic potential against four grain mold causing fungi of sorghum i.e. *F. moniliforme, A. alternata*, *C. lunata* and *P. sorghina*, by dual culture technique (Petkar, 2021) on PDA media along with the untreated inoculated control. Two streaks of *B. subtilis* isolate were placed 3cm apart on the media surface and 5mm disc of pathogenic fungi was placed at the centre with 3 replications for each combination. Thus inoculated Petri-plates were incubated at 27±2^{0}C for seven days. Per cent growth inhibition was calculated as per Charpe *et al.* (2017).

Statistical treatment of data

Data was subjected to analysis by Completely Randomized Design (CRD) using WASP-1.0 software of Central Coastal Agricultural Research Institute of Indian Council of Agricultural Research, Goa, India (ICAR-CCARI, 2024).

III. RESULTS

Isolation of grain mold causing fungi and pathogenicity test

Fungal cultures were isolated from grain mold infected field samples and were subjected to pathogenicity test. Amongst the collected fungal cultures *Fusarium moniliforme, Alternaria alternata, Curvularia lunata* and *Phoma sorghina* has proven the pathogenicity by molding the sorghum grains. So, they were maintained as axenic cultures on PDA for further experimentation.

Isolation of *B. subtilis* from phylloplane

Samples were collected from phylloplane during *kharif* and *rabi* seasons from sorghum, rice, cotton, soybean, pigeonpea and chilli crops etc. from various research units of Dr.PDKV, Akola, Maharashtra (Table 1). Collected samples were processed in the laboratory for isolation of *B. subtilis* on NA media by serial dilution technique. After three days of incubation, milky white colonies were observed which were later picked up and streaked on fresh NA plates for pure culture and used for further study. The data presented in Table 1 and Fig. 1 shows the crop-wise isolates of *B. subtilis* obtained from phylloplane samples of different field crops and were designated as PBs1, PBs2, PBs3, PBs4, PBs5 and PBs6, respectively.

Table 1. Isolation of phylloplane Bacillus subtilis from different crops and their morphological characterization

Crops	Locations	*B. subtilis* Isolate Number	Cell shape	Colony shape	Colony colour
Sorghum	Sorghum Research Unit, Dr. P.D.K.V., Akola	PBs1	Rod	Circular, Wet, Smooth, Concave	Dirty white
Rice	Sakoli	PBs2	Rod	Regular, Wet, Smooth, Entire margin	Dull white
Cotton	Cotton Research Unit, Dr. P.D.K.V., Akola	PBs3	Rod	Irregular, Dry, Smooth, Flat and Lobate margin	Slightly dirty white
Soybean	Pulses Research Unit, Dr. P.D.K.V., Akola	PBs4	Rod	Spreading, Wet, Smooth, Flat and Irregular with Lobate margin	Off white
Pigeonpea	Pulses Research Unit, Dr. P.D.K.V., Akola	PBs5	Rod	Circular, Wet, Smooth, Concave	Slightly white
Chilli	Chilli Research Unit, Dr. P.D.K.V., Akola	PBs6	Rod	Circular, Dry, Smooth, Flat and Irregular with Lobate margin	Transparent dirty white

Fig 1. Isolates of Bacillus subtilis on nutrient agar medium

Morphological characterization of phylloplane *B. subtilis* isolates

Bacterial cells of all the six phylloplane *B. subtilis* isolates appeared rod-shaped under 40x magnification of microscope. On NA media phylloplane *B. subtilis* developed as typical well-separated white colonies with a colour variation from creamy white to dirty white. Morphological characterization was done by classical macroscopic techniques of colour, elevation, form and shape of pure colonies. Most colonies were able to grow within 2-3 days when incubated at 25±2ºC temperature.

Biochemical characterization of phylloplane *B. subtilis* isolates

All the six phylloplane *B. subtilis* isolates were subjected to biochemical tests for their identification and further some tests were performed for comparison of the characteristics among isolates. Collected isolates were tested for shape, Gram's reaction, KOH solubility, starch hydrolysis, catalase test, gelatin liquefaction, H_2S production, casein hydrolysis, IAA production, MR test and acid & gas production.

Table 2. Biochemical properties of selected phylloplane Bacillus subtilis isolates

Sr. No	Character/ Properties	Reaction/ Isolates					
		PBs1	PBs2	PBs3	PBs4	PBs5	PBs6
1	Gram reaction	+	+	+	+	+	+
2	KOH test	-	-	-	-	-	-
3	Starch hydrolysis	+	-	+	-	+	+
4	Catalase test	+	+	+	+	+	+
5	Gelatinliquefaction	+	+	+	+	+	+
6	H_2S Production	+	+	+	+	+	+
7	Casein hydrolysis	+	+	+	+	+	+
8	Acid and Gas Production	+	+	+	+	+	+
A	Acid	+	+	+	+	+	+
B	Gas	-	-	-	-	-	-
9	IAA production	+	+	+	+	+	+
10	Phosphate solubilization	+	+	+	+	+	+
11	MR test	-	-	-	-	-	-

Fig. 2. Biochemical tests of collected Bacillus subtilis isolates

Efficacy of phylloplane *B. subtilis* isolates against sorghum grain mold fungal pathogens by dual culture technique

Data presented in Table 3, Fig. 3 and graphically represented in Fig. a, b, c and d indicated that all the isolates control the growth of *F. moniliforme*, *A. alternata, C. lunata and P. sorghina* with percent growth inhibition ranging between 65.99 – 77.09% in all six phylloplane isolates of *B. subtilis*.

Table 3. Efficacy of phylloplane Bacillus subtilis isolates against grain mold fungi of sorghum

Isolates	Host	Mean of mycelial growth of fungi in control (mm)	Mean of mycelial growth inhibition of fungi in treatment (%)
PBs1	Sorghum	29.16	62.42
PBs2	Rice	22.08	71.53
PBs3	Cotton	20.99	73.07
PBs4	Soybean	**18.75**	**75.91**
PBs5	Pigeonpea	24.17	68.84
PBs6	Chilli	25.75	66.87
Pathogen	Control	79.42	00.00

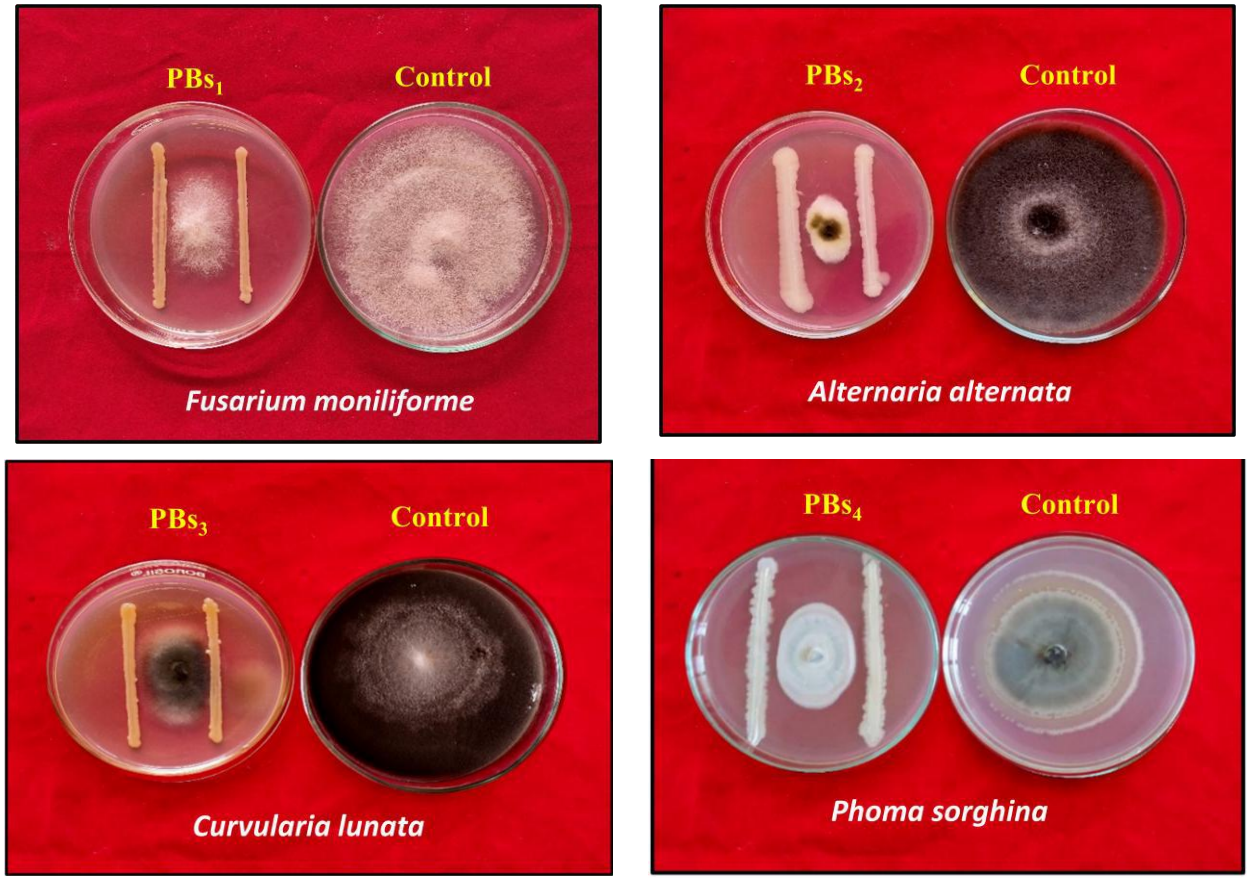


Fig 3. Efficacy of phylloplane Bacillus subtilis isolates against grain mold fungi of sorghum

IV. DISCUSSION

Isolation of grain mold causing fungi and pathogenicity test

All the four pathogenic genera *F. moniliforme, A. alternata, C. lunata* and *P. sorghina* obtained from molded grains of sorghum are earlier reported to cause Sorghum Grain Mold (SGM) Disease. Das *et al*. (2020) and Ackerman *et al*. (2021) have reported *F. moniliforme, A. alternata* and *C. lunata* as predominant pathogens responsible for SGM disease. Whereas, along with these three genera Thakur *et al*. (2006) has reported *Phoma sorghina* also as a fungal pathogen responsible for molding of sorghum grains. Thus, current findings are in agreement with the earlier reports.

Isolation of *B. subtilis* from phylloplane

The study supports the findings of earlier workers those have isolated *B. subtilis* from the phylloplane. Patro *et al.* (2002) recorded three isolates of phylloplane bacteria (Plb) (*Bacillus* spp.) from mungbean leaves. Brian (2004) isolated and reported that *B. subtilis* was the most abundant bacteria cultured from the phylloplane of soybean. Mohammadipour *et al.* (2009) studied the characterization of surfactin-producing 290 phylloplane isolates of *B. subtilis* collected from different ecological zones of Iran. Similarly, Theoduloz *et al.* (2003) reported that *B. subtilis* is a natural inhabitant of the tomato phylloplane. Pane and Zecardelli (2015) recorded 93 strains of *B. subtilis* spore-forming bacteria isolated from solanaceous phylloplane that were screened for *in vitro* antibiotic activity against *A. alternata* causal agent of tomato early blight. Sameer *et al.* (2018) had conducted studies to isolate potential phyllosphere colonizing antagonistic microbes (*B. subtilis*) for the management of *Fusarium* ear rot. Thus, the current study further confirmed the existence of *B. subtilis* in the phylloplane of different crops which have been reported by above referred workers.

Morphological characterization of phylloplane *B. subtilis* isolates

Data presented in Table-1 revealed that all *B. subtilis* phylloplane isolates were Gram-positive and rod-shaped. Similar results have been earlier reported by Perez (2000) and Toppo *et al.* (2015). These morphological characters confirm that the collected isolates were of *B. subtilis* bacteria.

Fig. (a). Efficacy of phylloplane Bacillus subtilis isolates against Fusarium moniliforme

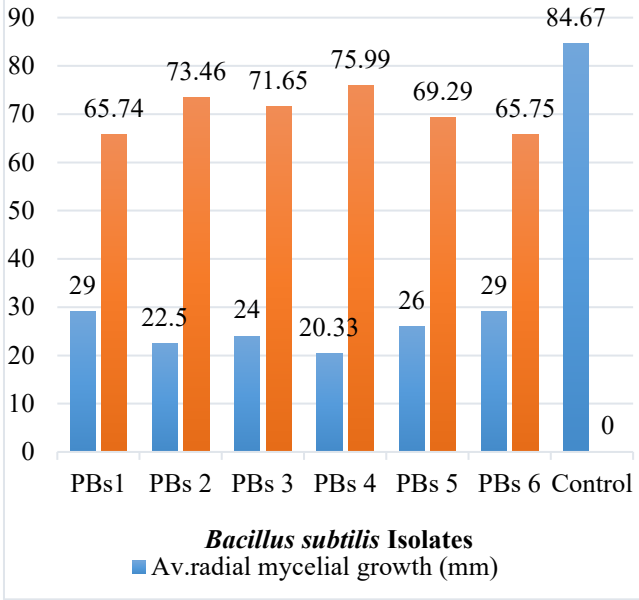


Fig. (b). Efficacy of phylloplane Bacillus subtilis isolates against Alternaria alternata.

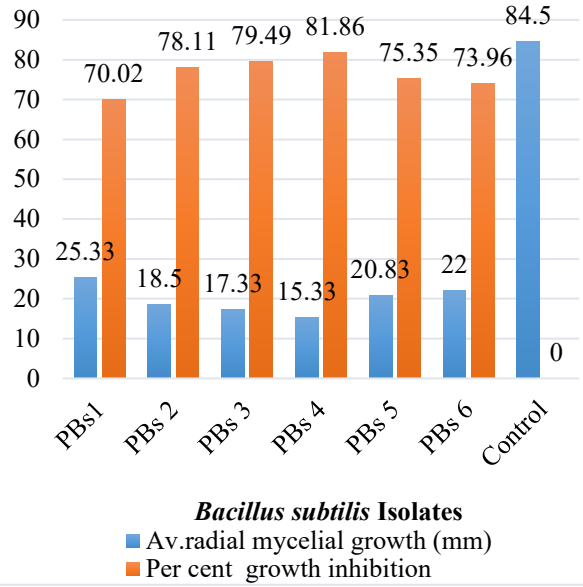


Fig. (c). Efficacy of phylloplane Bacillus subtilis isolates against Curvularia lunata

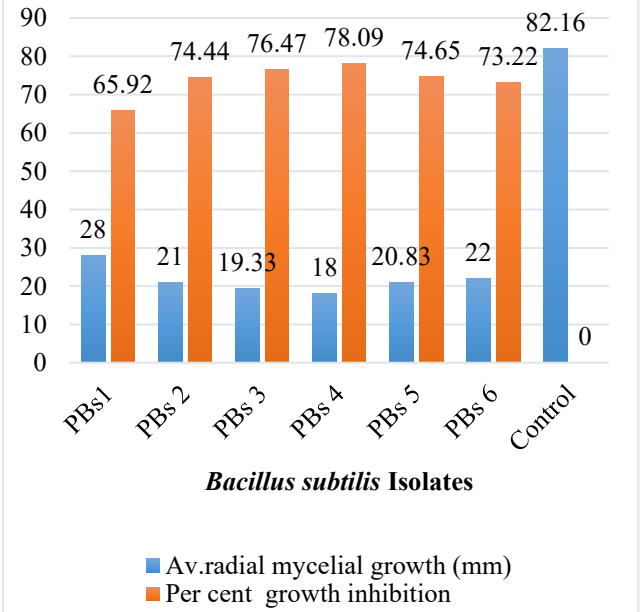
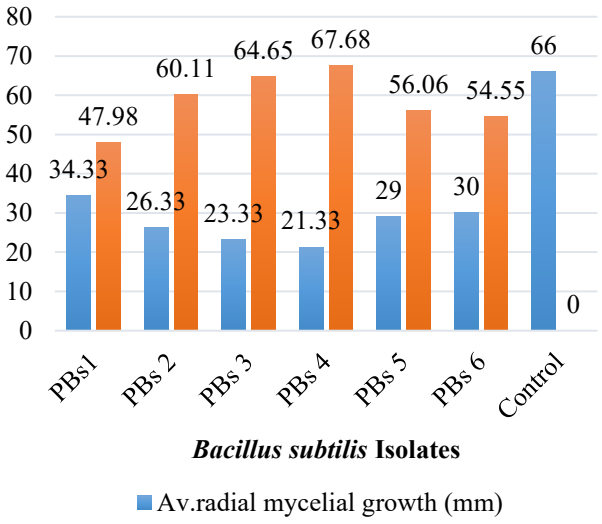


Fig. (d). Efficacy of phylloplane Bacillus subtilis isolates against Phoma sorghina



Here, minimum mycelial growth (18.75 mm) with maximum mycelial growth inhibition (75.91%) of *F. moniliforme, A. alternata, C. lunata* and *P. sorghina* was recorded in phylloplane isolate *B. subtilis* PBs4 followed by PBs3 (20.99 mm, 73.09%), PBs2 (22.08 mm, 71.53%) and PBs5 (24.17 mm, 68.84%). The other isolates of *B. subtilis* i.e.PBs6 and PBs1 were found least effective against all the fungal pathogens.

Biochemical characterization of phylloplane *B. subtilis* isolates

Data presented in Table 2 and Fig. 2 indicates that all the phylloplane *B. subtilis* isolates had positive reactions to Gram's reaction, starch hydrolysis, gelatin liquefaction, H_2S production, casein hydrolysis, catalase test, acid production and phosphate solubilization tests. Negative reaction was obtained for indole production, KOH solubility, MR test, acid & gas production and for starch hydrolysis test among the PBs2 and PBs4 isolates. This is

in agreement with the positive reactions with *B. subtilis* for starch hydrolysis, gelatin liquefaction, H_2S production, casein hydrolysis, catalase, phosphate solubilization and acid & gas production reported by Karimi *et al.* (2012), Abbo *et al*. (2014), Jadhav *et al*. (2014), Jha *et al*. (2016), Tariq *et al*. (2016). Avsar *et al*. (2017), Mandla *et al*. (2017) and Zhen xiang *et al*. (2018). Whereas, Willemse *et al.* (1980), Khan *et al.* (2011), Abbo *et al.* (2014) and Jha *et al*. (2016) has reported negative reactions regarding the KOH test, gas production, starch hydrolysis and indole production by *B. subtilis* that is also confirmed by the current results. The positive and negative results for biochemical tests of different *B. subtilis* isolates reported by the earlier workers confirmed the morphological and biochemical identification of the isolates under study.

Efficacy of phylloplane *B. subtilis* isolates against sorghum grain mold fungal pathogens by dual culture technique

The result of the present investigations is in agreement with the findings of Ghosh *et al.* (2014) who demonstrated antagonistic potential of *B. subtilis* against *F. moniliforme var. subglutinans in vitro* by dual culture plate method. They reported *Bacillus subtilis* strongly inhibited the growth of mycelium and spore germination of the pathogen and the non-volatile metabolites of *B. subtilis* had exhibited 72.00% inhibition of radial growth of fungal pathogen. Amaresan *et al.* (2012) reported *B. subtilis* isolates were effective against *Colletotrichum capsici* in chilli. Further, the suppression of mycelial growth of *C. gloeosporiodes* causing anthracnose in *Dendrobium* with crude extract of antifungal compound produced by *B. subtilis* was also reported by Prapagdee *et al.* (2012). The inhibition of *C. lindemuthianum* causing anthracnose of cowpea with different strains of *B. subtilis* (Bs-21, Bs-22 and Bs-23) was recorded by Adebanjo (2004). Laha and Venkantaraman (2001), Muralidharan *et al.* (2004) and Singh and Sinha (2004) reported inhibition of *C. lunata* causing black kernel in rice with *B. subtilis* (97.77%). Mycelial growth inhibition of *Curvularia geniculata* with antifungal compound produced by *B. subtilis* was reported by Dass and Teyegaga (1996). The strong inhibitory effect *in vitro* against *Phoma* spp. with *B. subtilis,* isolated from wheat phylloplane and suppression of *Myrothecium* spp. in watermelon with *B. pumilus* were reported by Perello *et al.* (2001) and Lokesh *et al.* (2007), respectively. These findings regarding antifungal activity of *B. subtilis* are confirmed by the results of the present investigation as well.

ACKNOWLEDGMENT

Authors acknowledge the Department of Plant Pathology, Dr.Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra, India for providing the laboratory facilities required for conducting this research.

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International Journal of Environment, Agriculture and Biotechnology
Vol-10, Issue-3; May-Jun, 2025
Peer-Reviewed International Journal
Journal Home Page Available: https://ijeab.com/
Journal DOI: 10.22161/ijeab

Effect of Nitrogen and Potassium Levels and Split Application on Growth, Yield, Nutrient Uptake, Soil Fertility, and Economics in Potato

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Received: 10 Apr 2025; Received in revised form: 09 Jun 2025; Accepted: 15 Jun 2025; Available online: 21 Jun 2025

Abstract— *A field experiment was conducted at the Plasticulture Development Farm, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar, Gujarat, India over three consecutive years to evaluate the impact of nitrogen (N) and potassium (K) fertigation levels and split applications on potato growth, yield, nutrient uptake, soil fertility, and economics. The experiment comprised three levels of N and K (including a control with 100% RDF through soil application) and three split application schedules (4, 6, and 8 splits), using sprinkler irrigation on ridge beds. The results indicated that applying 100% RDN and K through fertigation (F_3) significantly improved plant height, number of tubers per plant, and average tuber weight. The split fertigation schedule (S_3) consistently recorded higher tuber yield, nutrient uptake, and soil fertility levels. The highest marketable tuber yield (439.4 q/ha) and total yield (458.5 q/ha) were achieved under treatment F_3, while treatment S_3 closely followed with 443.5 q/ha. Economic analysis revealed maximum net returns of ₹273,652/ha (F_3) and ₹267,326/ha (S_3) with B: C ratios of 3.36 and 3.44, respectively. These findings suggest that fertigation using sprinkler systems with appropriate N and K levels and optimized split applications can significantly enhance potato productivity and profitability in water-limited regions.*

Keywords— ***Potato, fertigation, tuber yield, Nitrogen and Potassium***

I. INTRODUCTION

Potato (*Solanum tuberosum* L.), the fourth most important global food crop, is increasingly cultivated in semi-arid regions like North Gujarat using sprinkler irrigation systems. Fertigation—applying nutrients through irrigation—has gained traction as an efficient approach to enhance nutrient use efficiency, crop yield, and sustainability. In this practice, most of the nitrogen (N) and potassium (K) fertilizers are applied in multiple installments through sprinkler system, supplementing a basal dose applied at planting.

Fertigation improves fertilizer use efficiency by delivering nutrients directly to the active root zone, reducing losses and enhancing crop productivity and quality. It also minimizes environmental pollution and offers better flexibility in nutrient scheduling, especially in light-textured soils where conventional fertilization may lead to leaching and nutrient wastage.

In sprinkler-irrigated potato fields grown on ridge beds, fertigation using water-soluble N and K fertilizers ensures uniform application during different growth stages. In contrast, applying granular fertilizers after dense vegetative growth is difficult. Despite its increasing use, limited data are available to quantify the benefits. Therefore, this study was undertaken to evaluate the effect of different splits of N and K applied through sprinkler

fertigation on potato growth, yield, and economics.

II. MATERIALS AND METHODS

A field experiment was conducted for three consecutive years at the Plasticulture Development Farm, Centre for Natural Resources Management, Sardarkrushinagar Dantiwada Agricultural University (SDAU), Gujarat, India. The site is located in a semi-arid region (Agro-climatic Zone IV) at 24.32°N latitude, 72.32°E longitude, and 172 m elevation. The soil was loamy sand (84.65% sand, 7.20% silt, 7.90% clay) with pH 7.60, organic carbon 0.28%, available N 150 kg/ha, P_2O_5 33 kg/ha, and K_2O 181 kg/ha.

The experiment was laid out using large plot technique with gross and net plot sizes of 27 × 27 m and 4.5 × 4.0 m, respectively. It comprised three levels each of N and K, three fertigation splits, and a control with 100% RDF (275:138:275 N: P_2O_5: K_2O kg/ha) applied through soil. Fertilizer application included 25% N and K as basal and the rest through sprinkler fertigation in equal splits. Urea and sulphate of potash were used as N and K sources, while P_2O_5 was applied as basal.

Sprinkler systems (400 L/hr) were installed in 9 m × 9 m layout, operated for 4 hours at 2.5 kg/cm² pressure every 5–6 days, delivering 50 mm water per irrigation. Potato variety 'Kufri Pukhraj' was planted on raised beds with 20 × 20 cm spacing during the second week of November each year using an automatic planter.

Weed control was achieved using Metribuzin @ 500 g *a.i.*/ha as pre-emergence. Plant protection included spraying Imidacloprid @ 4 ml/10 L and Mancozeb (Dithane M-45) @ 2 kg/ha as needed. Haulm uprooting was done in the second week of February and harvesting in the third week.

Tuber yield was recorded, graded (<25 g and >25 g), and expressed in tonnes/ha. Economic analysis included calculation of total cost, gross and net returns, and benefit-cost ratio. Post-harvest soil samples were collected to assess nutrient status. Data were analyzed statistically to evaluate treatment effects.

III. RESULTS AND DISCUSSION

Effect on Growth and Yield Attributes

Emergence percentage and number of shoots per hill were not significantly affected by nutrient levels, consistent with findings by Singh *et al.* (2015), who reported that seed vigor and environmental conditions mainly govern early emergence. However, the split application significantly influenced shoot number, suggesting that timely nutrient supply can enhance vegetative proliferation (Kumar *et al*., 2018).

Plant height, a proxy for crop vigor, was significantly higher under F_3 (100% RDN & K) and with 8 splits (S_3). This aligns with the work of Pal *et al*. (2019), who demonstrated that adequate and well-timed N and K application promotes cell elongation and leaf expansion, resulting in taller plants.

The number of tubers per plant and average tuber weight were highest under F_3 and S_3 treatments. This supports the concept that both nutrient quantity and timing affect tuber initiation and bulking (Jones *et al*., 2014). Split applications likely maintain nutrient availability during critical stages, preventing early nutrient stress (Singh & Kumar, 2017).

Effect on Yield

The highest marketable and total tuber yields were recorded under full recommended nutrient doses applied in multiple splits. This finding corroborates previous reports by Sharma *et al*. (2016), who emphasized the positive correlation between nutrient management and tuber yield. Lower doses and fewer splits resulted in higher non-marketable yields due to smaller tubers, highlighting the importance of nutrient optimization for quality production.

Nutrient Uptake and Soil Fertility

Maximum N and K uptake was observed with higher nutrient levels and multiple splits, consistent with efficient nutrient absorption and utilization (Chaudhary *et al.,* 2020). Residual soil nutrient analysis revealed higher available N, P, and K under these treatments, indicating improved nutrient cycling and reduced losses (Patel & Singh, 2018).

Representation of nutrient uptake trends typically shows positive linear trends with nutrient levels and splits, reinforcing that nutrient management enhance both plant nutrition and soil fertility sustainability.

Economic Analysis

The economic analysis revealed that treatment F_3 yielded the highest net profit and a favorable benefit-cost ratio (BCR), demonstrating that higher input costs are offset by increased yields and revenue. The 8-split application (S_3) also showed superior profitability. These results align with Singh *et al.* (2019), who stressed that balanced fertilization maximizes returns on investment.

IV. CONCLUSION

The study confirms that applying 100% recommended doses of nitrogen and potassium, coupled with splitting the application into multiple doses (eight splits), substantially

improves growth parameters, tuber yield, nutrient uptake, soil fertility, and economic returns in potato production. These practices ensure nutrient availability aligns with crop demand, enhancing nutrient use efficiency and sustainable soil management.

Table 1. Emergence percent at 30 DAP, number of shoots per hill and plant height at 60 DAP of sprinkler irrigated potato under different treatments of fertigation scheduling (Pooled of three years)

Treatments	**Emergence (%)**	**Number of shoots per hill**	**Plant height at 60 DAP (cm)**
A) N and K levels			
F_1 : 50% RDN and K	90.59	4.71	90.89
F_2 : 75% RDN and K	90.26	4.80	91.44
F_3 : 100% RDN and K	89.78	4.89	88.89
S.Em. ±	**1.46**	**0.10**	**2.39**
C.D at 5%	**NS**	**NS**	**NS**
B) Number of Splits			
S_1 : 4 splits	89.48	4.57	90.00
S_2 : 6 splits	90.96	4.87	91.00
S_3 : 8 splits	90.19	4.94	90.22
S.Em. ±	**1.46**	**0.10**	**2.39**
C.D at 5%	**NS**	**0.30**	**NS**
Control v/s Rest			
Control	90.22	4.51	90.33
Rest	90.21	4.80	90.41
S.Em. ±	**1.88**	**0.13**	**3.09**
C.D at 5%	**NS**	**NS**	**NS**
Interactions : F x S	**NS**	**NS**	**NS**
Y × F, Y × S, Y × F × S	**NS**	**NS**	-
CV %	**8.40**	**11.38**	**7.94**

Table 2. Number of tubers and average weight of potato tuber under different treatments of fertigation scheduling (Pooled of three years)

Treatments	**Number of tubers/plant**	**Average weight of tuber (g)**
A) N and K levels		
F_1 : 50% RDN and K	4.60	101.1
F_2 : 75% RDN and K	5.40	122.9
F_3 : 100% RDN and K	5.83	141.2
S.Em. ±	**0.11**	**2.7**
C.D at 5%	**0.32**	**7.5**
B) Number of Splits		
S_1 : 4 splits	4.84	109.9
S_2 : 6 splits	5.41	120.4
S_3 : 8 splits	5.59	135.0
S.Em. ±	**0.11**	**2.7**
C.D at 5%	**0.32**	**7.5**
Control v/s Rest		
Control	4.39	102.7
Rest	5.28	121.7
S.Em. ±	**0.14**	**3.4**
C.D at 5%	**0.41**	**9.7**
Interactions : F x S	**NS**	**NS**
Y × F, Y × S, Y × F × S	**NS**	**NS**
CV %	**11.22**	**11.5**

Table 3. Tuber yield ≤25 g, >25 g and total tuber yield of sprinkler irrigated potato under different treatments of fertigation scheduling (Pooled of three years)

Treatments	**Tuber yield ≤25 g (q/ha)**	**Tuber yield >25 g (q/ha)**	**Total tuber yield (q/ha)**
A) N and K levels			
F_1 : 50% RDN and K	21.20	320.1	341.3
F_2 : 75% RDN and K	20.12	392.0	412.2

F_3 : 100% RDN and K	19.10	439.4	458.5
S.Em. ±	**0.50**	**6.2**	**6.1**
C.D at 5%	**1.42**	**17.7**	**17.4**
B) Number of Splits			
S_1 : 4 splits	21.23	341.4	362.7
S_2 : 6 splits	20.64	385.1	405.8
S_3 : 8 splits	18.54	425.0	443.5
S.Em. ±	**0.50**	**6.2**	**6.1**
C.D at 5%	**1.42**	**17.7**	**17.4**
Control v/s Rest			
Control	19.56	341.2	354.5
Rest	20.14	383.8	404.0
S.Em. ±	**0.65**	**8.0**	**7.9**
C.D at 5%	**NS**	**22.8**	**22.5**
Interactions : F x S	**NS**	**NS**	**NS**
Y × F, Y × S, Y × F × S	**NS**	**NS**	**NS**
CV %	**12.96**	**8.53**	**7.90**

Table 4. Nitrogen content in potato tuber & haulm and total N uptake by potato crop under different treatments of fertigation scheduling (Pooled of three years)

Treatments	**N content in potato tuber (%)**	**N content in potato haulm (%)**	**N uptake (kg/ha)**
A) N and K levels			
F_1 : 50% RDN and K	1.76	1.40	144.5
F_2 : 75% RDN and K	1.87	1.56	188.1
F_3 : 100% RDN and K	1.99	1.68	213.4
S.Em. ±	**0.02**	**0.02**	**3.5**
C.D at 5%	**0.05**	**0.06**	**10.0**
B) Number of Splits			
S_1 : 4 splits	1.83	1.47	157.9
S_2 : 6 splits	1.87	1.55	178.2
S_3 : 8 splits	1.92	1.62	209.8
S.Em. ±	**0.02**	**0.02**	**3.5**
C.D at 5%	**0.05**	**0.06**	**10.0**
Control v/s Rest			
Control	1.60	1.37	141.3
Rest	1.87	1.55	182.0
S.Em. ±	**0.02**	**0.03**	**4.5**
C.D at 5%	**0.06**	**0.07**	**12.9**
Interactions : F x S	**NS**	**NS**	**NS**
Y × F, Y × S, Y × F × S	**NS**	**NS**	NS
CV %	**4.86**	**6.80**	**10.3**

Table 5. Potassium content in potato tuber & haulm and total K uptake by potato crop under different treatments of fertigation scheduling (Pooled of three years)

Treatments	**K content in potato tuber (%)**	**K content in potato haulm (%)**	**K uptake (kg/ha)**
A) N and K levels			
F_1 : 50% RDN and K	2.48	3.17	223.2
F_2 : 75% RDN and K	2.65	3.60	292.4
F_3 : 100% RDN and K	2.80	3.80	327.7
S.Em. ±	**0.03**	**0.04**	**5.70**
C.D at 5%	**0.08**	**0.12**	**16.2**
B) Number of Splits			
S_1 : 4 splits	2.58	3.39	245.0
S_2 : 6 splits	2.67	3.53	278.7
S_3 : 8 splits	2.68	3.65	319.6
S.Em. ±	**0.03**	**0.04**	**5.70**
C.D at 5%	**0.08**	**0.12**	**16.2**
Control v/s Rest			
Control	2.33	3.05	225.5
Rest	2.64	3.52	281.1
S.Em. ±	**0.04**	**0.05**	**7.36**
C.D at 5%	**0.11**	**0.15**	**20.9**
Interactions : F x S	**NS**	**NS**	**NS**

Y × F, Y × S, Y × F × S	**NS**	**NS**	**NS**
CV %	**5.72**	**6.11**	**10.75**

Table 6. Available Nitrogen, phosphorus and potash in soil after harvest of potato as influenced by different treatment (Pooled of three years)

Treatments	**Available N (kg/ha)**	**Available phosphorus (kg/ha)**	**Available potash (kg/ha)**
A) N and K levels			
F_1 : 50% RDN and K	148.1	3.17	203.6
F_2 : 75% RDN and K	162.3	3.60	217.6
F_3 : 100% RDN and K	168.5	3.80	225.0
S.Em. ±	**1.8**	**0.04**	**2.9**
C.D at 5%	**5.0**	**0.12**	**8.2**
B) Number of Splits			
S_1 : 4 splits	154.1	37.32	209.4
S_2 : 6 splits	159.4	39.26	215.6
S_3 : 8 splits	165.3	41.28	221.1
S.Em. ±	**1.8**	**0.52**	**2.9**
C.D at 5%	**5.0**	**1.47**	**8.2**
Control v/s Rest			
Control	149.8	39.13	206.6
Rest	159.6	39.28	215.4
S.Em. ±	**2.3**	**0.67**	**3.7**
C.D at 5%	**6.4**	**NS**	**NS**
Interactions : F x S	**NS**	**NS**	**NS**
Y × F, Y × S, Y × F × S	**NS**	**NS**	**NS**
CV %	**5.8**	**6.84**	**7.0**

Table 7 Economics of potato under different treatments of fertigation scheduling

Treatment cost	**Tuber yield (q/ha)**	**Gross income ₹/ha**	**Total cost ₹/ha**	**Net Profit ₹/ha**	**BCR**
N and K levels					
50% RDN and K	341.3	290105	111361	178744	2.61
75% RDN and K	412.2	350370	113717	236653	3.08
100% RDN and K	458.5	389725	116073	273652	3.36
Number of Splits					
4 splits	362.7	308295	108149	200146	2.85
6 splits	405.8	344930	108899	236031	3.17
8 splits	443.5	376975	109649	267326	3.44
Control v/s Rest					
Control	360.7	306595	116448	190147	2.63

Selling price of Potato tuber ₹ 8.5 /kg

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International Journal of Environment, Agriculture and Biotechnology
Vol-10, Issue-3; May-Jun, 2025
Peer-Reviewed International Journal
Journal Home Page Available: https://ijeab.com/
Journal DOI: 10.22161/ijeab

Impact of Pesticide Exposure on Germination of Selected Legume and Cereal Crops Grown in Northeastern Nigeria.

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Received: 22 May 2025; Received in revised form: 19 Jun 2025; Accepted: 25 Jun 2025; Available online: 30 Jun 2025

Abstract— *The increasing adoption of chemical pesticides in sub-Saharan Africa has raised concerns among farmers about potential phytotoxic effects on staple crops. This study evaluated the impact of four commonly used products; Butaforce (butachlor), Glyweli (glyphosate), Kombat (lambda-cyhalothrin) and Weed Crusher (paraquat) on seed germination and early seedling growth (plumule and radicle) of cowpea (Phaseolus vulgaris), maize (Zea mays), pearl millet (Pennisetum glaucum), rice (Oryza sativa) and sorghum (Sorghum bicolor). Seeds were exposed to three concentrations (1.25, 2.5 and 5.0 ml L^{-1}) of each pesticide, with water-treated seeds serving as control. Data were subjected to one-way ANOVA at 5% significance level. Results showed that Kombat caused no significant reduction in germination or seedling growth; at 2.5 ml L^{-1} it even enhanced plumule and radicle elongation in cowpea, and at 5.0 ml L^{-1} further stimulated radicle growth relative to control. In contrast, Weed Crusher exerted the strongest inhibitory effect on both germination percentage and plumule/radicle development across all species. Butaforce and Glyweli also suppressed germination at higher concentrations, though to a lesser extent than Weed Crusher. These findings demonstrate that pesticide effects are both compound-specific and dose-dependent. Farmers are advised to integrate pesticide application within an integrated pest management framework to optimize crop productivity and environmental sustainability. Farmers can also integrate biocontrol agents into their crop protection strategies to reduce reliance on synthetic pesticides and mitigate phytotoxic risks.*

Keywords— ***Pesticide, Cereal, Legume, Germination***

I. INTRODUCTION

Food grains, often referred to as staple crops, play a pivotal role in global diets, serving as primary sources of carbohydrates, proteins, and other essential nutrients. According to the Food and Agriculture Organization (FAO), grains contribute more than 50% of the world's caloric intake (1). Common examples include rice, wheat, maize, barley, and oats, each offering distinct nutritional benefits; rice as a key energy source and wheat providing significant protein content. Sorghum and millet are high energy food sources and legumes like cowpea and Bambara groundnut are essential protein sources (2) Beyond their nutritional value, grains are integral to global food security due to their storability, enabling sustained food supplies during periods of scarcity (1). Additionally, cultivating diverse grain species supports sustainable agricultural systems by enhancing soil health, reducing erosion, and minimizing dependence on chemical fertilizers (3).

Crop production faces significant threats from a variety of biotic stressors, including insect pests, pathogenic fungi, viruses, and weeds. To mitigate these threats, both organic and synthetic pesticides are commonly applied in agricultural systems. These chemical agents, comprising fungicides, herbicides, nematicides, molluscicides, germicides, and antimicrobial compounds are widely used to safeguard crops (4). The global intensification of agricultural practices, particularly in developing countries,

has led to a marked increase in pesticide usage. Over the past decade, pesticide usage has risen by an estimated 153% increase in low-income countries (5). While many developed nations have banned the use of certain toxic and environmentally persistent pesticides, such substances remain in circulation in countries like Nigeria, where regulatory enforcement is less stringent (6). In Northern Nigeria, the influx of newly introduced pesticides, often lacking clear labeling and chemical composition disclosure especially concerning heavy metal content raises substantial concerns (7). Investigations have revealed that many pesticides in the region, although not officially banned by Nigeria's National Agency for Food and Drug Administration and Control (NAFDAC), contain hazardous elements such as Zn, Cd, Pb, Cu, and Cr (8, 9).

Synthetic pesticides are now deeply embedded in modern agricultural systems, particularly for the protection of vegetables and other high-value crops. While effective against pests and diseases, their widespread application has raised significant environmental and health concerns. These chemicals are associated with the development of pest resistance, biodiversity loss, pollution, and potential harm to human and animal health (10). Importantly, their toxic effects are not limited to target organisms. Emerging evidence suggests that synthetic pesticides can adversely affect non-target species, including crops, by disrupting growth, reproduction, and physiological functions (11). Studies have reported that pesticide exposure can impair pollen viability (12), interfere with plant reproductive processes (13), hinder plant growth and yield (14), reduce germination rates (15) and alter morphological and physiological traits (15, 16, 17). In particular, excessive use of fungicides has been linked to physiological disorders in plants (16), underscoring the potential for pesticides to negatively influence early plant development stages, such as germination.

The accumulation of pesticide residues and heavy metals in agricultural ecosystems presents a growing threat to food safety and environmental health. These contaminants are known to persist in food products and can enter the food chain through biomagnification, posing risks to both consumers and farmers (17). Heavy metals, in particular, are recognized as potent abiotic stressors, toxic to plants, animals, and humans alike (18, 19). Alarmingly, it is estimated that only about 1% of applied pesticides reach their intended targets, with the remaining 99% dispersing into the environment, contributing to environmental degradation (20). This inefficiency results in widespread contamination of soil and water resources, disruption of beneficial soil microbiota, and long-term ecological consequences (21, 22).

In light of these challenges, there is a pressing need to evaluate the unintended effects of commonly used pesticides on key agricultural crops, particularly during early developmental stages such as germination. This study investigates the effects of selected pesticides on the germination of cowpea and cereals widely cultivated in Northeastern Nigeria, with the aim of informing safer and more sustainable pest management practices.

II. MATERIALS AND METHODS

Study Area

This study was conducted at Abubakar Tafawa Balewa University, Bauchi, Nigeria (Latitude: 10.2791° N, Longitude: 9.7939° E). The university is located within the Bauchi metropolis, which serves as the administrative capital of Bauchi State in northeastern Nigeria. Bauchi lies on the northern edge of the Jos Plateau at an elevation of approximately 616 meters above sea level. The city covers an area of 3,687 km² and had a population of 493,810 according to the 2006 census.

Sample Collection

Five crop species; *Phaseolus vulgaris* (black-eyed cowpea), *Pennisetum glaucum* (pearl millet), *Oryza sativa* (Faro 44 rice), *Zea mays* (maize), and *Sorghum bicolor* (red sorghum) were procured from Muda Lawal Market in Bauchi metropolis. Samples were randomly collected from various vendors to ensure representativeness. The seeds were sorted by species, stored in polythene bags, and transported to the Ecology Laboratory at Abubakar Tafawa Balewa University for subsequent preparation and treatment.

Pesticide Treatments

Four commonly used pesticides were selected for the experiment; one insecticide (Kombat, containing Lambda-cyhalothrin) and three herbicides (Butaforce [Butachlor], Glyweli [Glyphosate], and Weed Crusher [Paraquat]). Each pesticide was prepared in three different concentrations: one at the manufacturer's recommended dose (medium concentration), one below, and one above the recommended dose.

The concentrations were prepared as follows:

- Butaforce (Butachlor)
  - Low: 4.69 mL/L (4.7×10^{-3} mL/mL)
  - Medium: 9.38 mL/L (9.4×10^{-3} mL/mL)
  - High: 18.75 mL/L (18.8×10^{-3} mL/mL)
- Glyweli (Glyphosate)
  - Low: 9.38 mL/L (9.4×10^{-3} mL/mL)

- Medium: 18.75 mL/L (18.8×10^{-3} mL/mL)
- High: 25.00 mL/L (25.0×10^{-3} mL/mL)

• Kombat (Lambda-cyhalothrin)

- Low: 1.25 mL/L (1.3×10^{-3} mL/mL)
- Medium: 2.50 mL/L (2.5×10^{-3} mL/mL)
- High: 5.00 mL/L (5.0×10^{-3} mL/mL)

• Weed Crusher (Paraquat)

- Low: 4.69 mL/L (4.7×10^{-3} mL/mL)
- Medium: 9.38 mL/L (9.4×10^{-3} mL/mL)
- High: 18.75 mL/L (18.8×10^{-3} mL/mL)

Each of the five crop species was treated with all three concentrations of the four pesticides in a completely randomized block design (RCBD). Treatments were replicated five times (pentaplicates), with each replicate consisting of five seeds, resulting in a total of 600 Petri dishes and 3,000 seeds.

Germination Assay

Seeds were surface-sterilized in 5% sodium hypochlorite (NaOCl) for 10 minutes and subsequently rinsed five times with sterile distilled water. Five uniform seeds were placed in each 110 × 20 mm Petri dish lined with Whatman No. 3 filter paper. For treatment dishes, 10 mL of the prepared pesticide solution was added, while control dishes received 10 mL of distilled water. All Petri dishes were sealed with parafilm to prevent moisture loss and incubated in the dark at room temperature for five days.

Data Collection and Analysis

At the end of the incubation period, germination percentage, mean germination time (MGT), mean germination rate (MGR), plumule length, and radicle length were measured. One-way Analysis of Variance (ANOVA) was conducted using Minitab software to assess the statistical significance of differences between treatment groups and controls for each measured parameter.

III. RESULTS

The effect of four different pesticides treatments on germination and seedling growth of *Zea mays, Phaseolus vulgaris, Pennisetum glaucum, Oryza Sativa* and *Sorghum bicolor* were evaluated.

The germination rate of *Zea mays* exhibited a general decline with increasing concentrations of the tested agro-pesticides (TABLE 1). Treatments with Butaforce (butachlor), Glyweli (glyphosate), and Weed Crusher (paraquat) resulted in a concentration-dependent reduction in germination percentage, plumule, and radicle lengths. Conversely, seeds treated with Kombat (lambda-cyhalothrin) showed an increase in plumule length with rising concentrations. The control group recorded the highest germination percentage and the longest plumule and radicle lengths across all treatments. At the lowest concentration of Butaforce (4.69 mL/L), *Z. mays* achieved 20% germination with a plumule length of 5.70 cm and a radicle length of 9.20 cm. At the intermediate concentration (9.38 mL/L), germination increased to 76%, but both plumule and radicle lengths decreased to 3.40 cm and 2.56 cm, respectively. No germination was observed at the highest concentration (18.75 mL/L). Glyweli-treated seeds showed 58% germination at 9.38 mL/L with 0.82 cm plumule and 0.46 cm radicle. Increasing the concentration to 18.75 mL/L and 25.00 mL/L reduced germination to 56% and 44%, respectively, with further reductions in plumule and radicle lengths. For Kombat treatments, the lowest concentration (1.25 mL/L) resulted in 60% germination, with plumule and radicle lengths of 4.22 cm and 7.62 cm, respectively. Germination increased to 72% at both 2.50 mL/L and 5.00 mL/L, with corresponding plumule lengths of 4.74 cm and 5.06 cm and radicle lengths of 5.54 cm and 5.80 cm. In Weed Crusher treatments, 4.69 mL/L yielded 24% germination, with 0.62 cm plumule and 0.82 cm radicle. At 9.38 mL/L, germination dropped to 20%, with further stunting of growth (0.36 cm plumule and 0.24 cm radicle). Complete inhibition of growth was observed at 18.75 mL/L.

Similarly, *Phaseolus vulgaris* demonstrated declining germination rates and stunted plumule and radicle growth with increasing concentrations of Butaforce, Glyweli, and Weed Crusher (TABLE 2). The control group consistently exhibited the highest values across all parameters, except in the Kombat treatment seeds. When treated with 4.69 mL/L of Butaforce, *P. vulgaris* showed a germination rate of 20%, no plumule development, and a radicle length of 1.82 cm. No germination occurred at higher concentrations (9.38 and 18.75 mL/L). In Glyweli treatments, the lowest concentration (9.38 mL/L) resulted in 40% germination with no plumule growth and 1.66 cm radicle. The higher concentrations yielded no plumule growth, with radicle lengths of 1.70 cm (18.75 mL/L) and 1.26 cm (25.00 mL/L). Kombat treatment had a contrasting trend. The highest concentration (5.00 mL/L) recorded the highest germination rate (40%), along with 2.04 cm plumule and 3.76 cm radicle lengths. The lower concentrations (1.25 and 2.50 mL/L) yielded lower germination but showed varying plumule and radicle lengths. Notably, the middle concentration (2.50 mL/L) produced the longest plumule (2.50 cm) but had the lowest germination rate among the

Kombat-treated seeds. Treatments with Weed Crusher completely inhibited germination in *P. vulgaris*, with no observable plumule or radicle development. Overall, pesticide exposure led to significant inhibition of germination and early seedling growth in both *Zea mays* and *Phaseolus vulgaris*, with the exception of Kombat, which had comparatively less phytotoxic effects, particularly on *P. vulgaris*.

A general trend of decreasing germination was observed with increasing pesticide concentration in *Pennisetum glaucum* (TABLE 3). Treatments with Butaforce, Glyweli, and Weed Crusher showed a steady reduction in germination percentage, plumule, and radicle lengths. Conversely, Kombat treated seeds exhibited an increase in growth metrics with rising concentrations. The control group displayed 100% germination and the greatest plumule and radicle development. At 4.69 mL/L of Butaforce, 92% germination was recorded, accompanied by 0.40 cm plumule and radicle lengths. This dropped to 22% germination at 9.38 mL/L, with both plumule and radicle reduced to 0.10 cm. Complete inhibition of germination was observed at 18.75 mL/L.

Glyweli treatments showed a gradual decline; at 9.38 mL/L, germination was 40%, with 0.32 cm plumule and 0.24 cm radicle. At 18.75 mL/L, germination fell to 36% (0.24 cm plumule, 0.20 cm radicle), and further declined to 32% at 25.00 mL/L with reduced growth (0.12 cm plumule, 0.14 cm radicle). In contrast, Kombat-treated seeds showed relatively improved responses. At 1.25 mL/L, germination was 68%, with 0.66 cm plumule and 3.20 cm radicle. This increased to 80% at 2.50 mL/L, with 0.92 cm plumule and 5.00 cm radicle. Although germination dropped to 52% at 5.00 mL/L, plumule length reached 1.18 cm, while radicle measured 2.92 cm. Notably, 2.50 mL/L produced the highest germination and longest radicle growth. Weed Crusher completely inhibited germination at all tested concentrations. Overall, both plumule and radicle development were significantly stunted across treatments, except for radicles treated with Kombat.

For *Oryza sativa* (TABLE 4), germination rates declined with increasing concentrations of all pesticides tested. The highest values across all growth parameters were recorded in the control group. Exposure to 4.69 mL/L of Butaforce resulted in 20% germination, with 0.10 cm plumule and radicle lengths. No germination occurred at higher concentrations (9.38 and 18.75 mL/L). Glyweli treatments yielded 48% germination at 9.38 mL/L (0.18 cm for both plumule and radicle), decreasing to 36% at 18.75 mL/L (0.10 cm plumule and radicle) and 24% at 25.00 mL/L with no further reduction in growth. Kombat exposure showed a positive trend: both 1.25 mL/L and 2.50 mL/L resulted in 76% germination, with plumule and radicle lengths of 0.62 cm/1.90 cm and 0.60 cm/1.50 cm, respectively. At the highest concentration (5.00 mL/L), germination peaked at 84%, with a plumule length of 10.68 cm, although radicle length declined to 0.76 cm. All concentrations of Weed Crusher completely inhibited seed germination. Overall, plumule and radicle development in *O. sativa* were markedly reduced across most treatments, with partial exception for radicles in the lower concentrations of Kombat.

In *Sorghum bicolor* (TABLE 5), the effects of pesticide concentration on germination and seedling growth are detailed in TABLE 5. A concentration-dependent decrease in germination was evident across all treatments except Kombat. The control consistently exhibited the highest values for all parameters. At 4.69 mL/L of Butaforce, S. *bicolor* achieved 72% germination with 0.62 cm plumule and 0.52 cm radicle lengths. These values declined to 48% (0.48 cm plumule, 0.30 cm radicle) at 9.38 mL/L and further to 20% at 18.75 mL/L, with only 0.04 cm growth in both parameters. In Glyweli treatments, a germination rate of 92% was observed at 9.38 mL/L with 0.20 cm plumule and radicle, dropping to 76% at 18.75 mL/L and 64% at 25.00 mL/L, both with constant growth values of 0.20 cm. Interestingly, the 25.00 mL/L treatment recorded higher germination than 18.75 mL/L. Kombat-treated seeds consistently maintained high germination rates: 92% at both 1.25 and 5.00 mL/L and 88% at 2.50 mL/L. Plumule and radicle lengths were 3.46 cm and 6.24 cm (1.25 mL/L), 2.98 cm and 5.36 cm (2.50 mL/L), and 2.72 cm and 4.82 cm (5.00 mL/L), respectively.

Weed Crusher treatments significantly suppressed growth. At 4.69 mL/L, germination was 60% with 0.22 cm plumule and 0.16 cm radicle. Germination declined sharply to 20% at 9.38 mL/L (0.08 cm plumule and radicle), with no growth observed at 18.75 mL/L. Overall, plumule and radicle growth were markedly reduced in all treatments, except for the radicles of *S. bicolor* exposed to Kombat, which retained considerable growth across concentrations.

IV. DISCUSSION

Pesticides, including herbicides, insecticides, and fungicides, are extensively utilized in agricultural systems to manage pests and enhance crop productivity. However, improper application or excessive concentrations can adversely affect seed germination and early seedling development. Several studies have demonstrated that certain pesticides disrupt enzymatic activity, alter

hormonal signaling, and negatively impact soil microbial communities, collectively impairing germination and seedling vigor.

The findings of this study indicate that pesticide exposure significantly influences the germination and early growth of *Zea mays*, with the extent of phytotoxicity varying by pesticide type and concentration. Among the tested agrochemicals, Butaforce (butachlor) and Weed Crusher (paraquat) exhibited the highest toxicity, completely inhibiting germination at their maximum concentrations. In contrast, Kombat (lambda-cyhalothrin) had comparatively milder effects, resulting in only moderate reductions in germination and seedling growth. Notably, reductions in both plumule and radicle length across treatments underscore the detrimental effects of pesticide stress on seedling vigor, with radicle inhibition particularly severe in treatments with Glyweli (glyphosate) and Weed Crusher. These results are consistent with previous findings where pesticides such as chlorantraniliprole significantly reduced coleoptile and radicle length in maize seedlings in Turkey (23). Similarly, fungicide exposure has been associated with impaired germination and biomass accumulation in Cicer arietinum and *Zea mays* in India (24).

In *Phaseolus vulgaris*, herbicidal stress led to pronounced inhibition of both germination and seedling growth, especially under exposure to Butaforce and Weed Crusher. Complete inhibition at higher concentrations suggests interference with critical physiological processes such as enzymatic activity and hormonal regulation during germination. This inhibition of germination observed in this study aligns with reports of oxidative stress and reduced chlorophyll content in *P. vulgaris* following herbicide application (25). Interestingly, selective inhibition of plumule elongation, even when radicle growth persisted (as observed with low concentrations of Butaforce and Glyweli), indicates differential tissue sensitivity to chemical stressors. Kombat treatments resulted in minimal adverse effects, with some concentrations even promoting radicle elongation compared to the control. This aligns with earlier studies indicating stimulatory effects of lambda-cyhalothrin on plant growth, including enhanced root development in rice (26) and cowpea (27). Contrastingly, other studies in Pakistan have shown that lambda-cyhalothrin can affect seed germination and seedling growth in tomato plants, especially at higher concentrations (28). Another study conducted in Nigeria have also shown that at low concentrations, cypermethrin can stimulate radicle growth in cowpea (29).

Butaforce and Weed Crusher caused the most pronounced reductions in germination and seedling growth, particularly at higher concentrations. Butaforce completely inhibited seedling growth at its highest tested level, likely due to interference with cell division and elongation processes. This is consistent with previous studies in *Triticum aestivum,* where butachlor exposure resulted in chromosomal aberrations and a reduced mitotic index (30). While Glyweli exhibited moderate toxicity, Kombat treatment led to better germination and growth performance, even at elevated concentrations, suggesting that lambda- cyhalothrin may be less phytotoxic to *P. glaucum.* Weed Crusher, however, demonstrated complete inhibition of seedling development.

Oryza sativa showed substantial susceptibility to Butaforce and Weed Crusher, with both herbicides markedly suppressing germination at all concentrations. Butaforce completely inhibited germination at higher concentrations, indicative of disruption to key cellular mechanisms such as mitosis and elongation. Glyweli exerted less severe effects, with partial reductions in germination and growth, while Kombat exhibited minimal phytotoxicity. Notably, the highest Kombat concentration was associated with the greatest germination rate and plumule length, further supporting potential growth-promoting effects of lambda-cyhalothrin at sublethal doses. In contrast, Weed Crusher caused complete inhibition at all tested concentrations. Paraquat is known to induce reductions in chlorophyll content and early seedling mortality in rice according to a research conducted in Mississippi (31).

Pennisetum glaucum responded variably to pesticide exposure, with Butaforce and Weed Crusher causing the most significant suppression of germination and growth. Butaforce exhibited concentration dependent toxicity, markedly reducing both plumule and radicle elongation. This result aligns with previous reports linking herbicidal phytotoxicity to the disruption of metabolic pathways essential for seedling development (30). Although Glyweli had less pronounced effects on germination, it inhibited growth of plumule and radicle particularly at higher concentrations. Kombat (lambda-cyhalothrin) had little toxicity even at higher concentrations. While specific studies on lambda-cyhalothrin's phytotoxicity on *Pennisetum glaucum* are limited, its comparatively lower impact suggests its possibility to be less toxic to plants or more suited to the crop's physiology. Weed Crusher (paraquat) exhibited complete inhibition of seedling development, indicating strong phytotoxic effects. According to a study in Algeria, paraquat is known to induce oxidative stress in plants, leading to diminished

chlorophyll content and reduced shoot and root biomass, as observed in fenugreek seedlings (32).

Growth of Sorghum bicolor was significantly stunted in across all pesticide treaments except for the radicle growth in plants treated with kombat (lambda-cyhalothrin). Similar inhibitory effects were observed in other studies where glyphosate and paraquat treatments resulted in significantly reduced growth of *Sorghum bicolor* (17). A study conducted in Ghana reported that high concentrations DDT and lambda-cyhalothrin significantly reduced seed germination rate and seedling vigor in vegetables (33).

Overall, the results of this study demonstrate that pesticide induced phytotoxicity is both species and compound-specific, with herbicides generally exerting more detrimental effects than insecticides. While some agrochemicals such as lambda-cyhalothrin may exhibit growth-promoting effects at low concentrations, others such as paraquat and butachlor are consistently associated with severe inhibition of early plant development. These findings underscore the importance of carefully selecting and managing pesticide application to minimize ecological harm and ensure optimal crop establishment.

Table 1. Seed germination and mean plumule and radicle growth of *Zea mays* exposed to pesticides after 5 days.

Concentration (ml/L)	Germination(%)	MGT(days)	MGR	Mean ± SD (cm)	
				Plumule	Radicle
Control	88	2.14	0.47	5.70 ± 1.56^{a}	9.20 ± 2.62^{a}
4.69 Butaforce	76	2.84	0.35	3.40 ± 1.74^{ab}	2.56 ± 0.66^{cd}
9.38 Butaforce	36	2	0.5	2.92 ± 2.12^{bc}	2.04 ± 1.26^{d}
18.75 Butaforce	0	0	0	0.00 ± 0.00^{d}	0.00 ± 0.00^{d}
9.38 Glyweli	44	2.36	0.42	0.82 ± 0.19^{cd}	0.46 ± 0.21^{d}
18.75 Glyweli	56	2.14	0.47	0.76 ± 0.37^{cd}	0.40 ± 0.10^{d}
25 Glyweli	56	2.64	0.38	0.66 ± 0.15^{cd}	0.38 ± 0.08^{d}
1.25 Kombat	60	2.44	0.41	4.22 ± 1.02^{ab}	7.62 ± 1.15^{ab}
2.5 Kombat	72	2.11	0.47	4.74 ± 0.96^{ab}	5.54 ± 1.36^{bc}
5 Kombat	72	2.33	0.43	5.06 ± 0.56^{ab}	5.80 ± 1.02^{bc}
4.69 Weed Crusher	24	2.17	0.46	0.62 ± 0.44^{cd}	0.82 ± 0.59^{d}
9.38 Weed Crusher	20	3.4	0.29	0.36 ± 0.21^{d}	0.24 ± 0.22^{d}
18.75WeedCrusher	0	0	0	0.00 ± 0.00^{d}	0.00 ± 0.00^{d}

Means in the same column that do not share a letter are significantly different at $P \leq 0.05$

Table 2. Seed germination and mean plumule and radicle growth of *Phaseolus vulgaris* exposed to pesticides after 5 days.

Concentration (ml/L)	Germination(%)	MGT(days)	MGR	Mean ± SD (cm)	
				Plumule	Radicle
Control	65	3.69	0.27	2.20 ± 0.93^{a}	3.32 ± 1.06^{ab}
4.69 Butaforce	20	2	0.5	0.00 ± 0.00^{b}	1.82 ± 1.09^{bcd}
9.38 Butaforce	0	0	0	0.00 ± 0.00^{b}	0.00 ± 0.00^{d}
18.75 Butaforce	0	0	0	0.00 ± 0.00^{b}	0.00 ± 0.00^{d}
9.38 Glyweli	40	2	0.5	0.00 ± 0.00^{b}	1.66 ± 0.40^{bcd}
18.75 Glyweli	36	2	0.5	0.00 ± 0.00^{b}	1.70 ± 0.48^{bcd}
25 Glyweli	26	2	0.5	0.00 ± 0.00^{b}	1.26 ± 0.46^{cd}
1.25 Kombat	36	2.33	0.43	1.72 ± 0.98^{a}	2.50 ± 0.59^{abc}
2.5 Kombat	32	2	0.5	2.50 ± 1.57^{a}	3.36 ± 0.62^{ab}

5 Kombat	40	2	0.5	2.04 ± 1.16[a]	3.76 ± 1.88[a]
4.69 Weed Crusher	0	0	0	0.00 ± 0.00[b]	0.00 ± 0.00[d]
9.38 Weed Crusher	0	0	0	0.00 ± 0.00[b]	0.00 ± 0.00[d]
18.75 Weed Crusher	0	0	0	0.00 ± 0.00[b]	0.00 ± 0.00[d]

Means in the same column that do not share a letter are significantly different at P≤0.05

Table 3. Seed germination and mean plumule and radicle growth of *Pennisetum glaucum* exposed to pesticides after 5 days.

Concentration (ml/L)	**Germination(%)**	**MGT(days)**	**MGR**	**Mean ± SD (cm)**	
				Plumule	**Radicle**
Control	96	2.21	0.45	3.36 ± 0.80[a]	5.10 ± 1.47[a]
4.69 Butaforce	88	4.41	0.23	0.26 ± 0.09[bc]	0.26 ± 0.09[bc]
9.38 Butaforce	20	5	0.2	0.10 ± 0.00[bc]	0.10 ± 0.00[c]
18.75 Butaforce	0	0	0	0.00 ± 0.00[c]	0.00 ± 0.00[c]
9.38 Glyweli	64	2.38	0.42	0.30 ± 0.10[bc]	0.36 ± 0.05[bc]
18.75 Glyweli	56	2.29	0.44	0.26 ± 0.05[bc]	0.26 ± 0.05[bc]
25 Glyweli	52	2.54	0.39	0.26 ± 0.09[bc]	0.26 ± 0.05[bc]
1.25 Kombat	76	2.32	0.43	1.00 ± 0.26[b]	4.60 ± 1.19[a]
2.5 Kombat	64	2.38	0.42	0.74 ± 0.27[bc]	5.20 ± 0.86[a]
5 Kombat	68	3	0.33	0.76bc ± 0.27[bc]	2.24 ± 1.55[b]
4.69 Weed Crusher	0	0	0	0.00 ± 0.00[c]	0.00 ± 0.00[c]
9.38 Weed Crusher	0	0	0	0.00 ± 0.00[c]	0.00 ± 0.00[c]
18.75 Weed Crusher	0	0	0	0.00 ± 0.00[c]	0.00 ± 0.00[c]

Means in the same column that do not share a letter are significantly different at P≤0.05

Table 4. Seed germination and mean plumule and radicle growth of *Oryza sativa* exposed to pesticides after 5 days.

Concentration (ml/L)	**Germination(%)**	**MGT(days)**	**MGR**	**Mean ± SD (cm)**	
				Plumule	**Radicle**
Control	96	3.17	0.32	1.58 ± 0.67[a]	2.44 ± 1.09[a]
4.69 Butaforce	20	5	0.2	0.10 ± 0.00[b]	0.10 ± 0.00[d]
9.38 Butaforce	0	0	0	0.00 ± 0.00[b]	0.00 ± 0.00[d]
18.75 Butaforce	0	0	0	0.00 ± 0.00[b]	0.00 ± 0.00[d]
9.38 Glyweli	48	4.17	0.24	0.18 ± 0.04[b]	0.18 ± 0.04[cd]
18.75 Glyweli	36	5	0.2	0.10 ± 0.00[b]	0.10 ± 0.00[d]
25 Glyweli	24	5	0.2	0.10 ± 0.00[b]	0.10 ± 0.00[d]
1.25 Kombat	76	3.63	0.28	0.62 ± 0.28[b]	1.90 ± 0.64[ab]
2.5 Kombat	76	3.84	0.26	0.60 ± 0.24[b]	1.50abc ± 0.90[abc]
5 Kombat	84	3.57	0.28	0.68 ± 0.24[b]	0.76 ± 0.18[bcd]
4.69 Weed Crusher	0	0	0	0.00 ± 0.00[b]	0.00 ± 0.00[d]
9.38 Weed Crusher	0	0	0	0.00 ± 0.00[b]	0.00 ± 0.00[d]
18.75 Weed Crusher	0	0	0	0.00 ± 0.00[b]	0.00 ± 0.00[d]

Means in the same column that do not share a letter are significantly different at P≤0.05

Table 5. Seed germination and mean plumule and radicle growth of *Sorghum bicolor* exposed to pesticides after 5 days.

Concentration (ml/L)	Germination (%)	MGT (days)	MGR	Mean ± SD (cm)	
				Plumule	Radicle
Control	92	2	0.5	5.86 ± 0.98[a]	6.82 ± 1.46[a]
4.69 Butaforce	72	2.33	0.43	0.62 ± 0.37[c]	0.52 ± 0.19[b]
9.38 Butaforce	48	4.17	0.24	0.48 ± 0.23[c]	0.30 ± 0.10[b]
18.75 Butaforce	20	5	0.2	0.04 ± 0.05[c]	0.04 ± 0.06[b]
9.38 Glyweli	92	2.35	0.43	0.20 ± 0.00[c]	0.20 ± 0.00[b]
18.75 Glyweli	64	2	0.5	0.20 ± 0.00[c]	0.20 ± 0.00[b]
25 Glyweli	76	2	0.5	0.20 ± 0.00[c]	0.20 ± 0.00[b]
1.25 Kombat	92	2.39	0.42	3.46 ± 0.83[b]	6.24 ± 0.96[a]
2.5 Kombat	88	2.91	0.34	2.98 ± 0.77[b]	5.36 ± 2.04[a]
5 Kombat	92	3.04	0.33	2.72 ± 0.96[b]	4.82 ± 2.21[a]
4.69 Weed Crusher	60	4.47	0.22	0.22 ± 0.16[c]	0.16 ± 0.06[b]
9.38 Weed Crusher	20	5	0.2	0.08 ± 0.04[c]	0.08 ± 0.05[b]
18.75 Weed Crusher	0	0	0	0.00 ± 0.00[c]	0.00 ± 0.00[b]

Means in the same column that do not share a letter are significantly different at P≤0.05.

Fig 1. *Zea mays* treated with Butaforce, Glyweli, Kombat and Weed crusher from top to bottom respectively (increasing concentration from left to right) with the solitary dish being the control

Fig 2. *Phaseolus vulgaris* treated with Butaforce, Glyweli, Kombat and Weed crusher from top to bottom respectively (increasing concentration from left to right) with the solitary dish being the control.

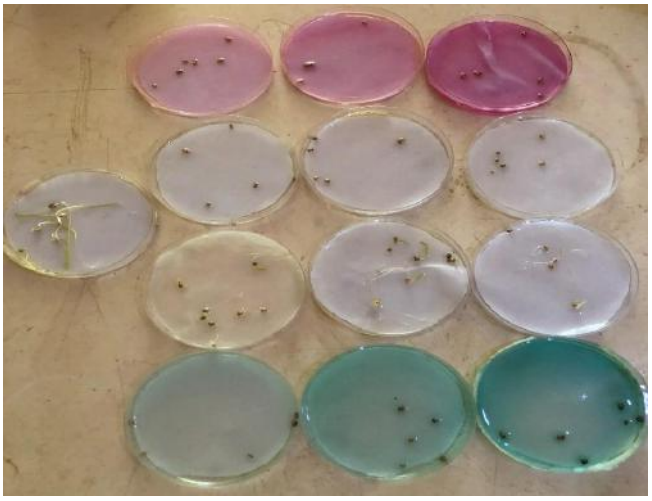

Fig 3. *Pennisetum glaucum* treated with Butaforce, Glyweli, Kombat and Weed crusher from top to bottom respectively (increasing concentration from left to right) with the solitary dish being the control.

Fig 4. *Oryza sativa* treated with Butaforce, Glyweli, Kombat and Weed crusher from top to bottom respectively (increasing concentration from left to right) with the solitary dish being the control.

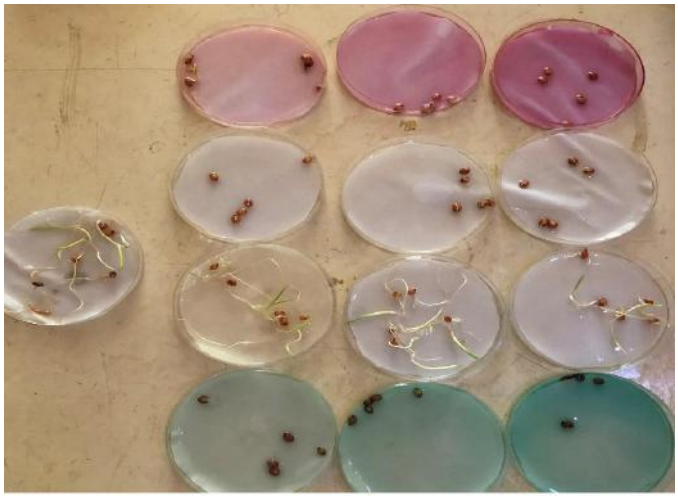

Fig 5. *Sorghum bicolor* treated with Butaforce, Glyweli, Kombat and Weed crusher from top to bottom respectively (increasing concentration from left to right) with the solitary dish being the control.

V. CONCLUSION

The findings of this study highlight the differential phytotoxic effects of various pesticide concentrations on the germination and early seedling growth of selected crop species. While certain pesticides, such as Kombat (lambda-cyhalothrin), exhibited growth-promoting effects at lower concentrations, others particularly Weed Crusher (paraquat) caused pronounced inhibitory effects on both plumule and radicle development, especially at higher concentrations. These results emphasize the importance of dose-dependent responses and crop-specific sensitivity to pesticide exposure. Given the potential for adverse developmental impacts, further investigations are warranted to evaluate the environmental persistence, residual toxicity, and selectivity of these agrochemicals. A comprehensive understanding of their physicochemical properties, formulation types, and interactions with plant physiological processes is essential for sustainable crop production. Farmers are encouraged to seek guidance on integrated pest management (IPM) practices to reduce dependency on chemical pesticides and enhance sustainability. Biocontrol agents such as entomopathogenic bacteria can also be integrated into crop protection strategies to reduce reliance on synthetic pesticides and mitigate phytotoxic risks.

ACKNOWLEDGEMENTS

We would like to thank the Department of Ecology, Abubakar Tafawa Balewa University, Bauchi, for providing Laboratory space for the study. This work was

supported by the TETfund research grant, TETF/DR&D/CE/UNI/AZARE/IBR/2023/VOL1.

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International Journal of Environment, Agriculture and Biotechnology
Vol-10, Issue-3; May-Jun, 2025
Peer-Reviewed International Journal
Journal Home Page Available: https://ijeab.com/
Journal DOI: 10.22161/ijeab

Impact of Hypoxic Root Zone Conditions on Growth and Survival of Black behi Pechay (*Brassica rapa* L.) Under Bacnotan, La Union, Philippines

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Received: 23 May 2025; Received in revised form: 21 Jun 2025; Accepted: 27 Jun 2025; Available online: 30 Jun 2025

Abstract— *Waterlogging, often caused by excessive rainfall, threatens crop productivity by depriving roots of oxygen. Pechay is a vital crop for food security, capable of producing significantly more food per unit area than cereal crops. This study assessed the growth response of Black Behi under different waterlogging durations (0, 24, 48, and 72 hours). Two weeks after sowing, seedlings were transplanted into polyethylene pots and grown for another two weeks before submersion. The study found that pechay plants, particularly the Black Behi variety, reacted differently depending on how long they were submerged in water. Those exposed to waterlogging for 72 hours (T_3) had the lowest survival and recovery rates, along with the poorest growth in terms of plant height and number of leaves. In contrast, plants submerged for only 24 hours showed growth nearly equal to those that were not submerged at all (T_0), suggesting that pechay can tolerate brief flooding. Overall, the results indicate that Black Behi pechay can withstand waterlogging for up to 48 hours (T_2) without major damage. These insights are valuable for farmers aiming to grow flood-tolerant pechay, especially in areas frequently affected by heavy rains or short-term flooding. The study suggests that pechay can tolerate waterlogging for up to 48 hours, but prolonged submersion negatively impacts plant development and survival. These findings are useful for guiding flood-resilient pechay cultivation.*

Keywords— ***Black behi, Hypoxic, Pechay, Subnersion, Waterlogging***

I. INTRODUCTION

In the Philippines, agriculture remains a backbone of the economy, providing food, employment, and income—especially in rural communities. Among the many vegetables grown locally, *pechay* (*Brassica rapa* L.) stands out as a popular leafy green due to its short growing cycle, nutritional value, and adaptability. It plays a key role in household food security and contributes significantly to the income of smallholder farmers.

Pechay which belongs to the Brassiceae family, is one of the most famous vegetables in the Philippines. It is also thought to be one of Asia's first green vegetables. As a result, it has a considerable impact on the Philippine economy and the nutrition of the Filipino people. Pechay is used mainly for its soft, young, yet thoroughly developed leaves. The succulent petioles are frequently chosen. Soups and stir-fried dishes contain it as a primary ingredient. Its green petioles and leaves are sometimes used as a garnish in cuisine (Rubia, 2024).

Black Behi is other variety of pechay which is adapted to both lowland and highland. This selection has proven adaptability in a wide range of Philippine climatic

conditions. It is selected for weight and uniformity. The plants are vigorous and large, forming thick petioles originating from its broad, thick, and compact base (East-West Seed, 2024).

Waterlogging creates hypoxic conditions in the root zone, meaning oxygen becomes limited in the soil. Without adequate oxygen, root respiration and nutrient absorption are impaired, leading to stunted growth, poor yield, or even crop failure. This condition forces the plant to switch to anaerobic respiration, which is inefficient and damaging over time.

As climate change increases the frequency of extreme rainfall and flooding, these hypoxic conditions are expected to become more common. Understanding how different pechay varieties respond to waterlogged and oxygen-deficient soils is therefore crucial. This study aims to assess the performance of pechay variety Black behi under hypoxic root zone conditions to help determine the maximum number of hours can pechay survive to waterlogging stress and support more climate-adaptive vegetable farming in the Philippines.

II. METHODOLOGY

2.1 **Research Design**

The study was laid out following simple Randomized Complete Block Design with three blocks and 6 sample plants per treatment per block. The treatments are as follows:

T_0 – Control (Non-submersion)

T_1 – 24 Hours

T_2 – 48 Hours

T_3 – 72 Hours

2.2 Procedures

2.2.1 Seed sowing and seedling preparation

Two to three (2–3) seeds of pechay seeds were sown per hole in seedling trays filled with fine, ordinary garden soil. The trays were placed under nursery conditions. After two (2) weeks, healthy and uniform seedlings were selected and transplanted into individual plastic pots measuring 4 x 6 inches. The seedlings were maintained under the nursery for another two (2) weeks to ensure proper establishment before treatment application.

2.2.2 Waterlogging Treatments

Waterlogging conditions was simulated using *lona*-lined submersion ponds. Each potted seedlings were carefully submerged in water, ensuring that the entire shoot is covered with water without submerging the leaves entirely. Water levels were regularly checked and adjusted to ensure they consistently reached the plant shoot level across all treatments.

The experiment followed a staggered submersion schedule to ensure that all treatments concluded simultaneously. Plants in T_3, assigned to the 72-hour submersion treatment, were submerged first. After 24 hours, plants in T_2, designated for 48-hour submersion, were submerged. On the third day, plants in T_1 underwent the 24-hour submersion treatment. Meanwhile, the control treatment (T_0) was not submerged but were placed adjacent to the submersion ponds to ensure they were exposed to similar environmental conditions as the submerged treatments.

After completing their designated submersion durations, plants from each subplot were removed from the *lona* ponds and returned to the observation area beside the pond. The plants were arranged following their original positions during the submersion process to maintain uniform exposure and arrangement throughout the observation period.

For the post submersion observation, all potted plants were observed daily for a 3-day period. Parameters such as plant wilting, recovery, new leaf formation, and signs of stress or mortality were recorded. This observation period was assessed the short-term impact of waterlogging on plant recovery and survival.

III. RESULTS AND DISCUSSIONS

Percentage Survival at Post Submersion

It can be gleaned from the table that a significant difference exists in the percentage survival of pechay subjected to varying submersion durations. A perfect survival rate (100%) was observed among plants under the control treatment, which were not submerged in water. This result is statistically comparable to the plants that were submerged for only 24 hours, suggesting that short-term submersion does not significantly affect the survival of pechay. Plants submerged for 48 hours exhibited a slightly lower survival rate of 87.01%, which was still statistically comparable to those submerged for 24 hours (92.58%). This suggests that pechay may possess a level of tolerance to brief periods of waterlogging, likely due to its ability to maintain oxygen transport and root function under mildly hypoxic conditions.

However, a marked decline in survival rate was noted at the 72-hour submersion level, with only 72.18% of plants surviving. This result supports the hypothesis that prolonged submersion has detrimental effects on pechay, potentially due to anoxic stress, impaired root respiration, and reduced nutrient uptake. According to Herzog et al. (2016), in their study on wheat (*Triticum aestivum)*

prolonged flooding leads to oxygen deficiency in the root zone, which adversely affects plant metabolism and can lead to cellular damage or death. The decrease in survival after 72 hours of submersion indicates that this duration surpasses the tolerance threshold for pechay under the experimental conditions.

Table 1. Percentage Survival of Black behi Pechay as Affected by Submersion Period

Treatments	Percentage Survival at Post Submersion Period (%)*
T_0 – Control (Not Submerged)	100.00[a]
T_1 – 24 Hours	92.58[ab]
T_2– 48 Hours	87.01[b]
T_3 – 72 Hours	72.18[c]

*=significant at $p < 0.05$. Means with the same letter are not significantly different; means with the same letters are significantly different.

This trend aligns with the findings of Pang et al. (2017), who reported that Brassica crops, including pechay and Chinese cabbage, experience significant reductions in survival and biomass accumulation under waterlogged conditions exceeding 48 hours. Similarly, Yamauchi et al. (2018) noted that oxygen deprivation in root tissues under extended flooding causes the accumulation of toxic metabolites and limits aerobic respiration, which are critical for cell maintenance and survival.

Conversely, some studies suggest that certain cultivars or varieties of leafy vegetables exhibit greater tolerance to waterlogging. For example, research by Ahmed et al. (2013) on mustard greens (a close relative of pechay) demonstrated high survival rates even after 72 hours of flooding, particularly when the plants were in earlier developmental stages. These discrepancies could be attributed to genetic variation, differences in root architecture, and physiological adaptations such as adventitious rooting.

The observed results in this study highlight the sensitivity of pechay to prolonged submersion, emphasizing the need for water management strategies during periods of heavy rainfall or poor drainage. The findings also suggest the importance of screening and selecting pechay varieties with greater flood tolerance for areas prone to waterlogging.

Initial Plant Height

Table 2 shows the plant height of Black behi pechay (*Brassica rapa* L.) before 72-hour submersion period. The initial plant height, recorded two weeks after sowing, showed no statistically significant differences among the varieties. This indicates that all pechay varieties exhibited relatively uniform growth under normal conditions prior to the application of the submersion treatment.

The absence of significant differences in initial plant height suggests that pechay used in the study have comparable early growth vigor and morphological development when grown under the same environmental and agronomic conditions. This uniformity is crucial in ensuring that subsequent differences observed post-treatment can be attributed to the imposed submersion stress rather than inherent differences in initial plant growth. According to Gomez and Gomez (1984), ensuring homogeneity in initial measurements is essential in treatment-response studies to validate the reliability of the experimental results. Furthermore, early plant height is often influenced by genetic factors, seedling vigor, and uniform cultural practices such as nutrient availability, irrigation, and light exposure (Taiz et al., 2015).

Final Plant Height

Analysis of Variance showed a significant difference in plant height at 72 hours post-submersion. A particularly noteworthy result was that plants under the control treatment (non- submerged) reached the tallest height of 114.50 cm and the only treatment that showed an increase in height after 72 hours. In contrast, all submerged plants either decreased in height or showed a little growth. The decline in height was most pronounced in plants submerged for 72 hours.

Interestingly, the plants submerged for only 24 hours experience a very little decrease in height (0.3cm), indicating that their physiological functions were already affected, albeit not to a destructive extent. This stagnation suggests that even short-term submersion can disturb normal plant metabolic activities such as cell elongation and nutrient transport.

Waterlogging or submersion affects plant growth by limiting oxygen availability in the root zone, which is crucial for aerobic respiration. Oxygen deprivation leads to a decline in root metabolic activity, causing reduced nutrient uptake and inhibition of hormone-regulated growth processes such as gibberellin-induced stem elongation (Setter & Waters, 1996). According to Jackson and Colmer (2005), hypoxic conditions resulting from waterlogging suppress cell division and elongation, thereby halting vertical growth. Similarly, Dat et al. (2004) noted that prolonged submersion triggers ethylene accumulation and reactive oxygen species (ROS)

formation, which in turn leads to oxidative stress and leaf senescence.

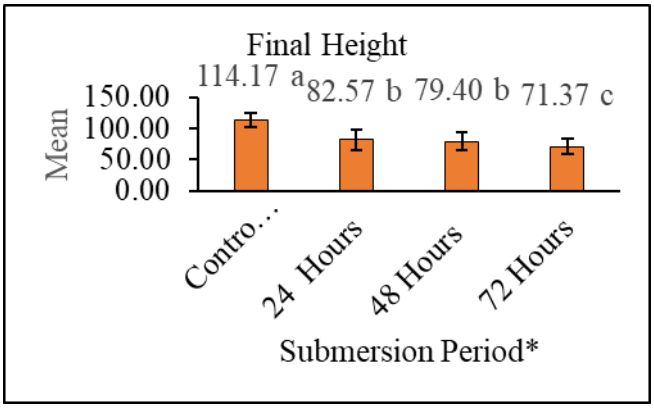

Fig. 1. Final Plant Height

In a study on *Brassica* crops, Malik et al. (2002) observed that plant height and biomass accumulation were significantly reduced after 48 to 72 hours of waterlogging. These findings are consistent with the present results, where extended submersion caused visible signs of stress and growth retardation.

In summary, the observed reduction or stagnation in plant height under submerged conditions confirms that waterlogging severely impairs physiological processes essential for plant development. The lack of oxygen disrupted hormonal signaling, and stress responses collectively contribute to growth inhibition and in some cases, deterioration of plant structure (Herzog et al., 2016).

Leaf Number

As to the final number of leaves gathered at the post-submersion period after 72 hours, analysis of variance revealed a significant difference among treatments as can be gleaned from Figure 2. This indicates that the duration of submersion had a measurable impact on the leaf number of pechay. It can be observed that plants under the control treatment (no submersion) continued to produce new leaves, demonstrating normal vegetative growth under non-stress conditions. In contrast, all plants subjected to submersion—whether for 24, 48, or 72 hours—exhibited a decrease in the final number of leaves compared to their initial counts. This decline in leaf number among submerged plants can be attributed to several physiological responses to flooding stress. Submersion limits oxygen availability to plant tissues, leading to hypoxic or anoxic conditions that impair aerobic respiration, damage cellular structures, and hinder growth processes (Bailey-Serres & Voesenek, 2008). As a result, energy production becomes inefficient, and leaf senescence or abscission may be triggered as a survival mechanism (Jackson & Colmer, 2005).

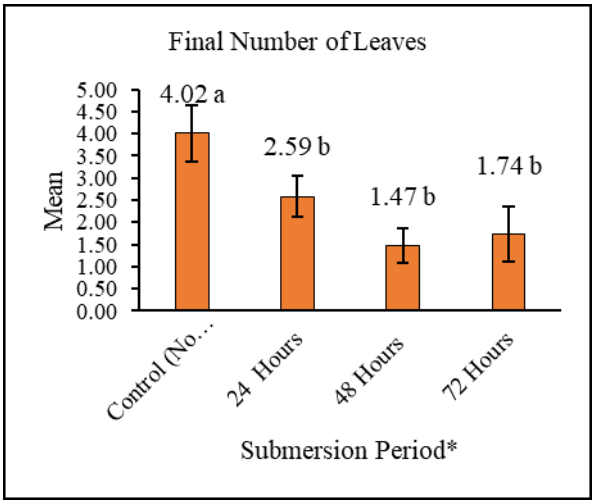

Fig. 2. Leaf Number

*=significant at $p< 0.05$. Means with the same letter are not significantly different; error bars represent standard deviation.

Percentage Survival Recovery

The results of the analysis of variance showed very highly significant differences among the treatment groups. Unsurprisingly, plants in the control group—those not submerged at all—had a 100% survival rate. These were statistically similar to the plants submerged for just 24 hours, which still managed a high recovery rate of 98.15%. However, survival dropped sharply in plants submerged for 72 hours, suggesting that longer submersion severely hampers the plants' ability to recover.

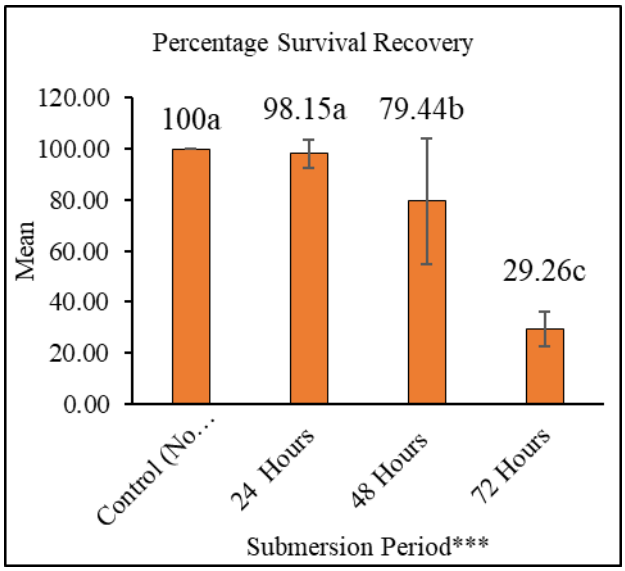

Fig. 3. Percentage Survival Recovery

***=very highly significant at $p< 0.05$. Means with the same letter are not significantly different; error bars represent standard deviation.

This pattern points to a strong inverse relationship between the length of submersion and the chances of plant survival. The longer the pechay plants stayed underwater, the less likely they were to survive. This finding is consistent with the work of Jackson and Ram (2003), who noted that prolonged flooding limits the oxygen plants need to breathe and produce energy, making it harder for them to survive. Colmer and Voesenek (2009) also highlighted how waterlogged conditions affect root function and cause stress due to lack of oxygen—something particularly challenging for crops like pechay that are not naturally adapted to wet environments.

It is worth noting that plants can cope with short-term flooding, like 24 hours, by temporarily slowing down their metabolism, closing their stomata, and using up stored energy. But when the flooding lasts too long, these coping mechanisms are no longer enough. That is when we start to see signs of serious stress like leaf yellowing

and tissue damage, which explain the low survival rate in the 72-hour treatment (Yamauchi et al., 2018). Malik et al. (2014) made similar observations in their research, showing that different crops have varying limits when it comes to surviving under water, depending on how well they can maintain internal balance and oxygen flow.

IV. CONCLUSION

Pechay plants submerged for 72 hours exhibited significantly lower percentage survival, reduced recovery survival percentage, shorter plant height, and fewer leaves during the post-submersion period. This indicates that prolonged waterlogging severely affects the physiological and morphological performance of pechay, limiting its ability to recover and resume normal growth after stress. Pechay variety Black behi can tolerate waterlogged conditions for up to 24 hours. Submersion beyond this period can significantly inhibit growth and development, leading to detrimental effects on the crop.

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International Journal of Environment, Agriculture and Biotechnology
Vol-10, Issue-3; May-Jun, 2025
Peer-Reviewed International Journal
Journal Home Page Available: https://ijeab.com/
Journal DOI: 10.22161/ijeab

Traditional Indian Methods to Preserve Food

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Received: 25 May 2025; Received in revised form: 20 Jun 2025; Accepted: 25Jun 2025; Available online: 30 Jun 2025

Abstract— *India has a long tradition, spanning thousands of years, of preserving fruits, vegetables, cereals, and milk using natural methods that help extend their shelf life while maintaining their taste, nutritional value, and safety. India's traditional food preservation methods include sun drying, pickling, fermentation, smoking, and brining, which help extend the shelf life of fruits, vegetables, cereals, and dairy by controlling moisture and microbial growth. Additionally, techniques like granary storage, biopesticides, parboiling, roasting, and milk processing ensure the long-term safety and usability of grains, pulses, and dairy products. Various traditional techniques incorporate biological, chemical, and physical principles that prevent spoilage and microbial contamination. These traditional Indian preservation techniques have been passed down through generations and have helped communities survive food shortages and seasonal variations. These traditional Indian preservation techniques reflect the country's deep-rooted knowledge of natural food storage. They help reduce food waste, enhance flavors, and provide food security without relying on artificial preservatives. With the growing preference for organic and chemical-free food preservation, these age-old methods are regaining popularity in modern kitchens.*

Keywords— ***Cereals, Dairy, Fruits and Vegetables, Natural method, Preservation.***

I. INTRODUCTION

India has a long history of preserving fruits, vegetables, cereals, and milk using traditional techniques that ensure safety, extend shelf life, and enhance nutritional value. These methods, dating back thousands of years, are based on scientific principles such as moisture control, pH reduction, and microbial inhibition. The traditional Indian food preservation methods were sun drying, pickling, fermentation, and brining, which help extend the shelf life of fruits, vegetables, and spices by reducing moisture and microbial growth [1]. Smoking, roasting, and underground storage were used for preserving meat, cereals, and root vegetables by controlling temperature and humidity. Granary storage and natural biopesticides like neem leaves and turmeric protected grains from pests, while parboiling and drying (*Chawal Pakane aur Sukhaane ki Prakriya*) enhanced the longevity of rice. Dairy preservation techniques such as curdling (*Dahi banana*), butter making (*Makkhan banana*), ghee-making (*Makkhan se Ghee nikalna*), and milk reduction into *khoya* or powder ensured extended storage and usability of milk products. The preservation of fruits, vegetables, cereals, and dairy has played a critical role in sustaining Indian food traditions while reducing waste.

II. TRADITIONAL INDIAN METHODS TO PRESERVE FRUITS AND VEGETABLES

One of the most widely used preservation techniques is sun drying (*dhoop mein sukhaana*), practiced since the Indus Valley Civilization around 2000 BCE. This method reduces

the water activity (a_w) of food below 0.6, preventing microbial growth. Common sun-dried products include amchur (dry mango powder), *kasuri methi* (dried fenugreek leaves), and red chilies. Sun drying is particularly effective in hot and dry climates, requiring temperatures between 45–60°C for optimal drying.

Another popular method is pickling (achaar), which dates back to the Vedic period (1500–500 BCE). Pickles are preserved using high salt concentrations (15–20%) or acidic solutions that lower pH below 4.5, creating an environment unsuitable for spoilage organisms. Mango pickle, lemon pickle, and carrot-radish pickle are well-known examples [2]. Fermentation is another traditional method used in India to preserve food while boosting its nutritional value. Historical evidence suggests that fermentation was practiced in India as early as 1000 BCE, with references found in Ayurvedic texts describing the health benefits of fermented foods. *Kanji,* a probiotic-rich drink made from fermented black carrots and mustard seeds, is commonly consumed in North India. Similarly, *Gundruk*, made from fermented leafy greens, has been a staple in the Northeast for centuries. In some states, bamboo shoots are fermented and stored for later use in curries. Fermentation relies on beneficial lactic acid bacteria (LAB) to preserve food. Fermented products like *kanji* (fermented black carrot drink) and *gundruk* (fermented leafy greens) have a pH below 4.0, making them naturally resistant to harmful microbes [3]. Thus, fermentation not only extends shelf life but also supports gut health [4]. However, improper fermentation can lead to spoilage, making it essential to follow proper hygiene practices.

Brining (salt preservation) is another ancient technique that has been practiced for over 2000 years, particularly in coastal regions where salt was easily available. This technique prevents microbial growth and is commonly used in India to preserve vegetables like raw mangoes, bamboo shoots, and gooseberries (*amla*) [2, 5]. High salt concentration (20–25%) causes plasmolysis in microbial cells, preventing spoilage. Meanwhile, sugar syrup preservation, mentioned in Ayurvedic texts such as the Charaka Samhita (300 BCE–200 CE), uses high sucrose concentrations (60–70%) to reduce water activity ($a_w < 0.8$), preventing microbial growth. *Amla murabba* and mango *chutney* are common examples. In some regions, smoking (*Dhuan mein Sukhaana*) and roasting (*Bhunaai*/Parching) have been used for over 2000 years to preserve food by exposing it to phenol- and aldehyde-rich smoke, which has antimicrobial properties. Smoked red chilies and dried brinjal slices are traditional examples.

For long-term storage, root cellaring has been practiced for over 1000 years, particularly for root vegetables like potatoes, onions, garlic, and pumpkins. This method maintains cool temperatures (0–10°C) and high relative humidity (85–95%) to slow enzymatic activity and prevent spoilage.

III. TRADITIONAL INDIAN METHODS FOR CEREALS AND LEGUMES PRESERVATION

Beyond fruits and vegetables, cereal preservation has played a critical role in Indian agriculture. Parboiling and drying of rice, a technique developed over 2000 years ago, involves partially boiling rice in its husk before drying and milling. It gelatinizes starch and inactivates enzymes, improving storage stability. Parboiled rice has a lower moisture content (12–14%), reducing the risk of fungal growth. This method not only extends the shelf life but also improves the nutritional content of the rice. Traditional granary storage ((*Bhandaran*) involves keeping grains in mud bins, bamboo baskets, or metal silos at low humidity (<14%) and temperatures below 25°C to prevent mold and insect infestation. In rural India, grains like wheat, millet (*bajra*), sorghum (*jowar*), and lentils are often stored in bamboo baskets, earthen pots, or underground silos to keep them dry and prevent insect infestations. Aged rice (*pohoya*) was highly valued and stored for one to two years to enhance its texture and flavor. Traditional techniques such as mixing grains with neem leaves, ash, or dried red chilies were used as natural insect repellents [6]. Neem leaves and turmeric powder contain azadirachtin, which repels insects without the requirement of harmful insecticides/chemicals. Roasting (*Bhunaai*/Parching) helps extend the shelf life of cereals and pulses, with common examples including roasted *chana*, *murmura* (puffed rice), and roasted wheat.

IV. TRADITIONAL INDIAN METHODS TO PRESERVE MILK

Milk preservation in India also dates back to the Vedic period (1500 BCE) and includes techniques such as curdling, ghee-making, and dehydration. Fresh milk spoils quickly in a hot climate, so Indians developed techniques to convert milk into curd (*dahi*), butter, *ghee*, *paneer* (cottage cheese), *khoa* (reduced milk), and *chhana* (soft cheese). Curd (*dahi*) production involves fermenting milk with *Lactobacillus* bacteria at 35–42°C, reducing pH to 4.6 and ensuring preservation for 2–3 days. The process of making ghee (clarified butter), which involves boiling butter to remove moisture, was widely practiced in ancient India as a way to store dairy for months without refrigeration. It is made by heating *makkhan* to 110–120°C which removes moisture and prevents microbial growth, making it shelf-

stable for months [7]. *Ghee* was not only a staple in Indian cuisine but also had religious and medicinal significance in Ayurveda. *Khoa*, used in sweets like *gulab jamun, barfi*, and *peda*, is made by slow-cooking milk until it thickens and can be stored for weeks. *Chhena*, which is used in making Bengali sweets like *rasgulla* and *sandesh,* is another traditional dairy product that dates back centuries [6, 8]. *Khoa* and *chhena*, have moisture levels below 30% and 50%, respectively, ensuring longer shelf life.

Kheer is a traditional Indian dessert that has been enjoyed for centuries. It is a sweet rice pudding made with milk, rice, sugar, and flavored with cardamom, saffron, nuts, and sometimes rose water or kewra essence [9]. Kheer is deeply rooted in Indian culture and is often prepared during festivals, religious ceremonies, and special occasions like weddings and birthdays. *Kheer* has a long history in India, dating back to ancient times. It is believed that "Payasam" (a South Indian version of kheer) was offered as prasadam (sacred food) in temples like the Jagannath Temple in Odisha [10, 11]. The dish has also been mentioned in medieval Indian texts as a delicacy enjoyed in royal kitchens. Buttermilk (*chaas*) and whey (*takra*) are also commonly consumed traditionally as fermented dairy drinks that aid digestion [24].

V. SPECIALITY OF TRADITIONAL INDIAN METHODS OF FOOD PRESERVATION

Traditional Indian food preservation methods are natural, sustainable, and chemical-free because they rely on locally available resources, climate conditions, and time-tested techniques instead of artificial preservatives. Sun drying reduces moisture content, preventing microbial growth, while pickling and brining use high salt, oil, or acidic solutions to create an environment where spoilage organisms cannot thrive. Techniques like pickling, drying, and fermentation not only preserve food but also enhance its flavor, texture, and aroma. For example, sun-dried mango (*amchur*) adds a tangy taste to dishes, while aged pickles develop richer flavors over time. Fermentation encourages the growth of beneficial bacteria that naturally preserve food, enhance digestibility, and improve nutritional value [12]. Granary storage and biopesticides like neem leaves and turmeric protect grains from pests without harmful chemicals, and dairy preservation techniques such as curdling and ghee-making extend milk's shelf life naturally. Traditional food preservation reduces reliance on refrigeration and industrial processing, leading to lower energy consumption and a smaller carbon footprint. Techniques like sun drying, smoking, and underground storage are sustainable and do not require electricity, making them ideal for rural areas. Most of these methods are eco-friendly, cost-effective, and adaptable, ensuring food security and minimal wastage, especially in rural and agrarian communities.

Traditional methods are natural, cost-effective, and sustainable, making them ideal for preserving food in rural and resource-limited settings (Table 1). However, they require more time and careful storage conditions. Modern methods of food preservation involve use of thermal and non-thermal processing of foods. They offer precision, consistency, and extended shelf life, but they often depend on artificial additives and energy-intensive technologies. Thermal processing involves the application of heat to kill microorganisms, inactivate enzymes, and prevent spoilage [13]. Common thermal techniques include blanching, which briefly heats vegetables or fruits to inactivate enzymes before freezing; pasteurization, which mildly heats liquids like milk (72°C for 15 sec) to kill harmful bacteria while preserving quality; and sterilization, where foods like canned vegetables and UHT milk are treated at high temperatures (above 100°C) to eliminate all microbes. Other advanced methods like milk powder production involve spray-drying milk to achieve moisture levels of 2–4% and water activity below 0.2, making it highly resistant to spoilage. Methods such as dehydration and drying remove moisture to prevent microbial growth, while extrusion cooking processes cereals and snacks under high heat and pressure. Although thermal processing is highly effective, it can degrade heat-sensitive nutrients like Vitamin C and alter food texture, color, and taste. On the other hand, non-thermal processing preserves food without significant heat exposure, thereby maintaining freshness, nutrients, and sensory qualities. High-pressure processing (HPP) uses extremely high pressure (300–800 MPa) to destroy pathogens in foods such as cold-pressed juices [14, 15]. Pulsed Electric Field (PEF) processing applies short bursts of electricity to kill bacteria in liquids like milk and fruit juices [16]. Ultraviolet (UV) irradiation disinfects food surfaces, while ozone treatment extends the shelf life of meat and seafood [17]. Emerging techniques such as cold plasma technology use ionized gases to sterilize food packaging and fresh produce. While non-thermal methods offer significant advantages in preserving nutrients and reducing energy consumption, they often require high initial investment and may not be as effective against certain spores and enzymes.

Table 1. Comparison of Traditional and Modern Food Preservation Methods

Aspect	Traditional Methods	Modern Methods
Benefits		
Natural & Chemical-Free	Uses natural preservatives like salt, oil, sugar, and fermentation, making food safer and healthier.	Often involves artificial preservatives, which may have long-term health risks.
Nutritional Value	Retains essential nutrients and enhances bioavailability (e.g., fermentation increases probiotics).	Some methods, like freezing and vacuum sealing, retain nutrients well, but excessive processing may reduce them.
Eco-Friendly & Sustainable	Requires minimal energy, making it environmentally friendly (e.g., sun drying, smoking, root cellaring).	Uses advanced refrigeration, freezing, and packaging, leading to higher energy consumption and waste production.
Cost-Effective	Low-cost and accessible, especially in rural areas with minimal technology.	Expensive due to advanced machinery, packaging, and storage costs.
Flavour & Aroma	Enhances natural taste through aging, fermentation, and smoking.	Some methods (like canning and artificial preservatives) may alter the natural taste.
Long-Term Storage	Suitable for long-term storage of grains, dairy, and pickles without electricity.	Can extend shelf life for months or years with advanced refrigeration and vacuum sealing.
Disadvantages		
Time-Consuming	Methods like pickling, fermentation, and sun drying take days or weeks.	Faster preservation with techniques like flash freezing and dehydration.
Storage Limitations	Requires specific conditions (e.g., dry climate for sun drying, cool temperatures for root storage).	More versatile, as modern refrigeration allows preservation in any climate.
Control Over Microbial Growth	Relies on natural methods, which may not always prevent bacterial contamination.	More precise microbial control using sterilization, pasteurization, and preservatives.
Inconsistent Quality	Varies based on climate, skill, and storage conditions.	Standardized methods ensure uniform quality and consistency.
Shelf Life	Some methods (like curdling or brining) preserve food for weeks or months but not as long as freezing or canning.	Can preserve food for years using advanced techniques like freeze-drying and irradiation.

Table 2. Health Effects of Traditional vs. Modern Food Preservation Methods

Aspect	Traditional Methods (Sun Drying, Pickling, Fermentation, etc.)	Modern Methods (Freezing, Canning, Chemical Preservatives, etc.)
Nutritional Value	Retains or enhances nutrients through natural preservation (e.g., fermentation increases probiotics and vitamins).	Some methods, like freezing, retain nutrients, but excessive processing (e.g., canning, dehydration) may reduce vitamins.
Chemical Exposure	Uses natural preservatives like salt, sugar, oil, and fermentation, which have minimal side effects when consumed in moderation.	Often involves artificial preservatives (e.g., nitrates, sulfites, BHA, BHT), some of which have been linked to health risks like allergies and cancer.
Digestive Health	Fermented foods (like yogurt, pickles, kanji) promote gut health by providing beneficial probiotics.	Highly processed foods may lack fiber and probiotics, potentially leading to digestive issues.

Salt and Sugar Intake	Some traditional methods (e.g., pickling, *murabba*) use high salt or sugar, which can increase the risk of hypertension, diabetes, and heart disease.	Processed foods may contain excessive salt, sugar, or unhealthy fats, contributing to obesity and lifestyle diseases.
Additives & Allergens	Rarely contains artificial colors, flavors, or stabilizers, reducing the risk of allergies and food intolerance.	Some modern preservation techniques use additives (like MSG, artificial colors, and emulsifiers) that may trigger allergic reactions.
Microbial Safety	Some methods (like fermentation) introduce beneficial bacteria, but improper handling can lead to contamination.	More controlled sterilization processes ensure microbial safety, but improper packaging can still cause contamination (e.g., botulism in canned foods).
Cancer Risk	Minimal risk if naturally preserved; however, excessive intake of salt-preserved foods may be linked to stomach cancer.	Some preservatives (like nitrates in processed meats) are associated with an increased risk of cancer.

Traditional food preservation methods are generally healthier and more natural, but high salt or sugar intake in pickles and preserved sweets can pose health risks if consumed excessively [19, 20] (Table 2). Modern methods offer better microbial safety and extended shelf life, but artificial preservatives and processing can reduce nutritional value and contribute to long-term health issues [21, 22]. Application of traditional technologies such as fermentation and development of new value-added food products such as fortified foods, powders and soups help restore nutritional status of the growing population facing double burden of malnutrition [23, 24, 25, 26, 27]. A balanced approach, using both traditional and modern techniques wisely, ensures food safety while maintaining health benefits.

VI. CONCLUSION

These traditional Indian preservation techniques, many of which date back thousands of years, reflect the country's deep-rooted knowledge of food safety and storage. By leveraging scientific principles such as water activity control, pH reduction, enzyme inactivation, and microbial inhibition, these methods have ensured food security for generations. Today, modern processing industries continue to draw inspiration from these age-old techniques to develop sustainable and chemical-free preservation methods. As the demand for organic and naturally preserved food grows, these time-tested methods are finding renewed relevance in both rural and urban households.

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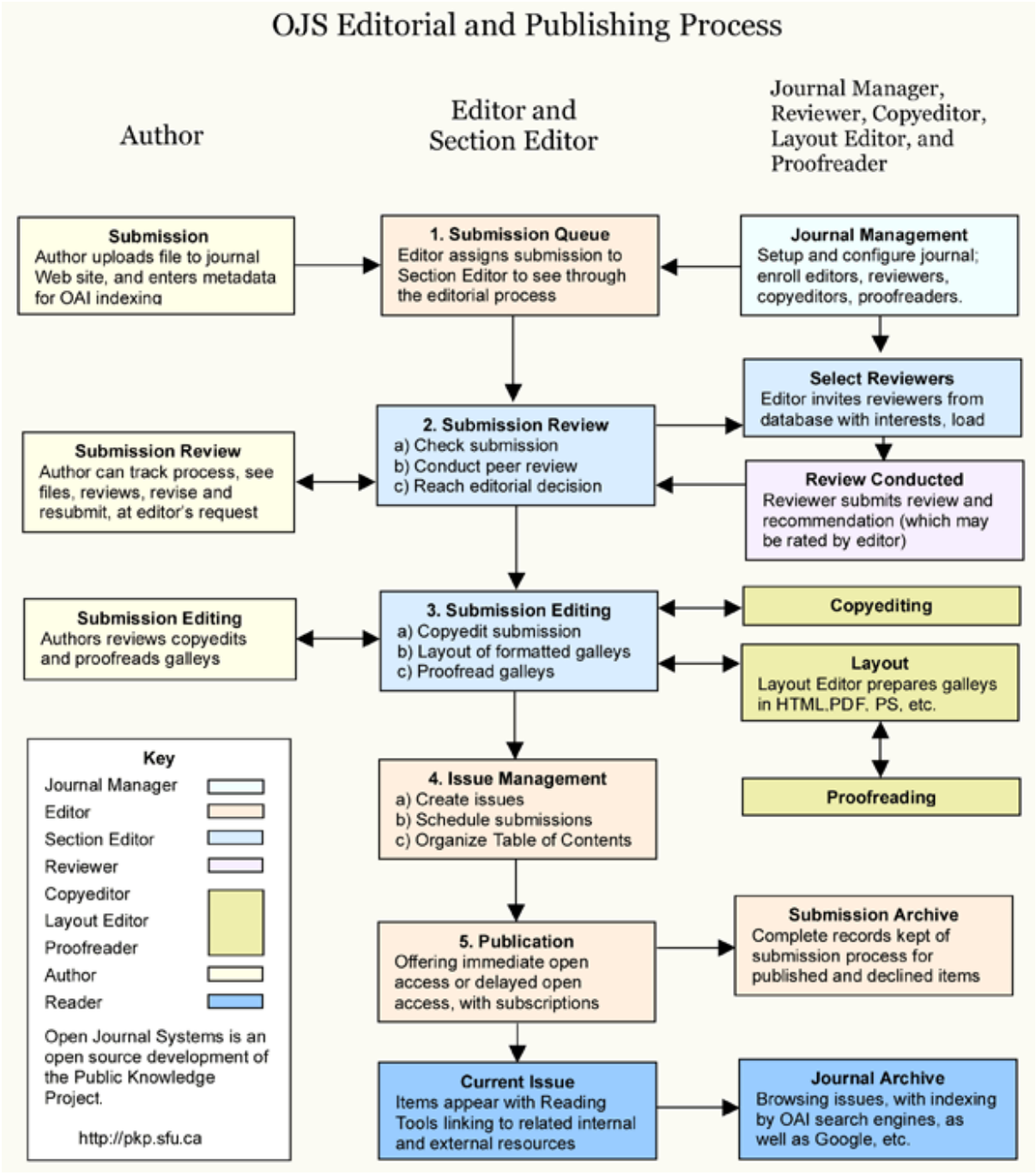

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