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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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Impact of Spraying with some Micronutrients on onion (*Allium Cepa* L.) Yield and Economics of Onion

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***Abstract*— *Micronutrients are essentially as important as macronutrients to improve growth, yield and quality in plants. Present experiment was conducted as on-farm testing at farmers' field during Rabi season of 2021-22, 2022-23 and 2023-24 to assess the impact of essential micronutrients like zinc, magnesium, copper, manganese, iron, molybdenum and boron spray on growth, bulb yield and economics of onion crop. Two treatments i.e. T_1- Farmers' practice (without spray) and T_2- foliar spray of ready-mix containing (Zn, Mg, Fe, Mn, Cu, Mo and Bo 0.25%) @ 2.5 ml/ litre at 30 and 45 days after transplanting of onion seedlings replicated at ten farmers field of Fatehabad district. The use of micronutrients as foliar spray was found effective in treatment T_2 with the significantly highest bulb weight (54.48, 55.60 & 57.20g), bulb yield (198, 265 & 300 q/ha) during 2021-22, 2022-23 and 2023-24, respectively. Maximum net return (₹ 104400, 323000 & 98000/ ha) and benefit cost ratio (2.93, 4.19 & 2.89) were recorded in the treatment T_2 whereas, in treatment T_1 (farmers' practices) net return were (₹ 91000, 292000 & 86500/ ha) and BC ratio (2.71, 3.92 & 2.69), respectively during 2021-22, 2022-23 and 2023-24. Therefore, the use of micronutrient application to be increases the production and recommended for onion cultivation.*

***Keywords*— Bulb yield, Economics, Foliar spray, Micronutrient, Onion**

I. INTRODUCTION

Among alliums, onion (*Allium cepa* L.) is one of the most widely grown commercial vegetable crop in India that belongs to family Amaryllidaceae [11]. It is mainly grown for bulb production and used as salad, spice in soups, curries, condiment or cooked with other vegetables, such as boiled or baked and also used in processed form (powder, pickles, paste and flakes). Onion or its product consumption has been found to be beneficial in several diseases such as cancer, cardiac, diabetes and respiratory diseases *etc*. [10]. Due to its highly valued flavor, aroma, unique taste and medicinal properties of its flavour compounds onion commonly known as "Queen of the kitchen" [14,8]. India is a major exporter of onion and is second largest producer in the world next to China. In India, the area under onion is 17.9 lakh ha with production of 302.08 lakh mt per annum with average productivity of 16.87 t/ha. In Haryana, the area under onion is 2.28 lakh ha with production of 5.43 lakh mt per annum with 23.79 t/ha productivity [3]. In India, major onion producing states are Maharashtra, Madhya Pradesh, Gujarat, Karnataka, Rajasthan, Bihar, West Bengal, Uttar Pradesh, Haryana, Andhra Pradesh, Tamil Nadu, Odisha, Punjab and Telangana.

Due to intensive cropping, a smaller amount of manures, micronutrients and unfair use of fertilizers so soil health is deteriorating continuously. All the essential nutrient elements are most important factors which govern the onion growth and yield. Macro and micronutrients help in increasing the yield, storage quality and fertility status of soil in onion. The macronutrient such as N, P, K, Ca, Mg, S and micronutrients such as Fe, Zn, Cu, B, Mo and Mn are beneficial in enhancing the growth, bulb yield, storage quality and fertility status of soil in onion (Singh, 2005). Indian soils are exposed to Multi-micronutrient deficiencies are closely associated with the yield and quality of crops, as proper plant nutrition is one of the most important factors in improving both the quality and quantity of plant products. Although micronutrients are required by plants in minor quantities, they are involved in a wide range of metabolic processes and cellular functions within plants. In addition, they play an essential role in improving crop growth and yield, as reported by various studies.

EI-Tohamyetal., 2009 and Alam et al., 20Intensive cropping, imbalanced fertilization and no use of micronutrients, less or no use of organic manures have resulted the depletion of soil fertility. Consequently, micronutrients statuses have been decreasing day by day and finally fertility status of soils have been declining. In India, soils are exposed to multi-micronutrient deficiencies that closely associated with the growth of crop and yield. Proper plant nutrition is one of the most important factors in improving the quality as well as quantity of plant products. The use of micronutrients by farmers is limited. Although, the micronutrients are required in very few quantity but play an active role in cell division and carbohydrates metabolism in plant growth and better crop yield (Kumar *et al.,* 2021).Smriti et al., 2002; Shinde et al., 2016 reported that micronutrients such as zinc, boron and ferrous increase the bulb size, highest plant height, bulb diameter, bulb fresh weight and yield of onion.

Indian soils are exposed to multi-micronutrient deficiencies that are closely associated with crop yield and quality. Proper plant nutrition is one of the most important factors in improving both the quality and quantity of plant products. Although micronutrients are required by plants in minor quantities, they are involved in a wide range of metabolic processes and cellular functions and play an essential role in enhancing crop growth and yield, as reported by El-Tohamy et al. (2009) and Alam et al. (2010). The production of good-quality onion bulbs is an important goal for onion growers, many of whom have inadequate knowledge about the beneficial role of micronutrients in increasing onion yield and quality for local and foreign markets. Bulb size and yield are enhanced when micronutrients are applied in combination rather than individually. Consequently, onion cultivation has expanded into newly reclaimed areas characterized by low fertility, high pH, and low organic matter content, leading to poor availability of micronutrients in the soil. Keeping this in view, a field experiment was conducted at the College of Horticulture (OUAT), Sambalpur, Odisha, India, during the Rabi season of 2014–15 to study the effect of micronutrients on onion growth and total bulb yield, with the primary objective of evaluating their efficacy on vegetative growth parameters and total bulb yield.

Soil health is continuously deteriorating due to intensive cropping system, less use of manures, micronutrients and injudicious use of fertilizers. All essential nutrient elements are most important factors which govern the onion growth, yield and its quality production. Macro and micronutrients help in improving the yield, storage quality and fertility status of soil in onion crop cultivation. The macronutrient such as N, P, K, Ca, Mg, S and micronutrients such as Fe, Zn, Cu, B, Mo and Mn enhance the growth, bulb yield, storage quality and fertility status of soil in onion [16,7]. The use of micronutrients is limited. Although, the micronutrients are required in very less quantity but have important role in cell division and carbohydrates metabolism in plant growth and high crop yield [10]. There were several evidences that micronutrients such as zinc, ferrous and boron increases bulb size, highest plant height, bulb fresh weight, bulb diameter and yield of onion [17,15]. In Haryana, most of the farmers use macronutrients especially nitrogen, phosphorus and potassium in vegetable crops. The farmers should carefully follow recommendations for micronutrients to avoid unnecessary costs and their toxic effects. Looking to the importance of micronutrient application, an attempt has been made to study on efficacy of micronutrient spray on growth, bulb yield and economics of onion.

II. MATERIALS AND METHODS

Present experiment was conducted as on-farm testing at farmers' field of Fatehabad district during *Rabi* season of 2021-22, 2022-23 and 2023-24 to assess the impact of foliar spray of essential micronutrients like zinc, magnesium, copper, manganese, iron, molybdenum and boron spray on growth, bulb yield and economics of onion bulb crop. Onion seed was treated with carbendazim 1 g/kg seed as per package of practices. The treated seed was sown in lines in well-prepared nursery beds in the first fortnight of November during every year of experiment. Nursery management operations (Thinning, weeding, irrigation) were carried out till seedling were transplant in field. Nursery was raised commonly for both the treatments and micronutrients were applied as per treatment. About 50-55 days old seedling of about 15 cm height were transplanted during first fortnight of January at a spacing of 15-20 x 10-15 cm. The recommended doses of fertilizer were applied. Two treatments *i.e.* T_1- Farmers' practice (without foliar spray of micronutrients) and T_2-

foliar spray of ready-mix containing (Zn, Mg, Fe, Mn, Cu, Mo and Bo 0.25%) @ 2.5 ml/ litre at 30 and 45 days after transplanting of onion seedlings comprising of 1.0 acre area as plot size of Fatehabad district. Demonstrations were regularly monitored at different stages of crop by a multi-disciplinary team of KVK scientists. Economics of onion crop production was calculated by keeping a record on each operation carried out, number of labour engaged, power and inputs utilized. The gross and net returns (Rupees per hectare) were calculated considering the prevailing market price of input and produce. Benefit cost ratio, represents the returns per rupee invested were worked out for different package of practices under each treatment by dividing gross returns with corresponding cost of cultivation.

Net returns = Gross returns - Cost of cultivation

Benefit to Cost ratio = Gross returns/ Cost of cultivation

III. RESULTS AND DISCUSSION

The effect of micronutrient foliar spray was studied on bulb weight (g), bulb yield and economics of onion. In present experiment use of foliar spray of micronutrients on onion crop was found effective in treatment T_2. This might be due to better efficacy of micronutrient mixture in increasing vegetative growth and bulb yield because micronutrients play a pivotal role in strengthening plant cell walls and translocation of carbohydrates from leaves to other plant parts indicates possibility of increasing dry matter percentage as well as yield [9].

3.1 BULB WEIGHT (G)

Application of micronutrients *i.e.,* treatment T_2- foliar spray of ready-mix containing (Zn, Mg, Fe, Mn, Cu, Mo and Bo 0.25%) (Table 1) had highest bulb weight (54.48, 55.60 & 57.20g) as compared to treatment T_1 (without spray of micronutrients) bulb weight (45.30, 47.50 & 48.40 g) during 2021-22, 2022-23 and 2023-24, respectively. Increased bulb weight was also due to enhanced growth and yield traits as a result of micronutrients applications. The result of present experiment well corroborates the findings of Abedin *et al*. (2012); De *et al.* (2013) and Pramanik *et al.* (2020) [1,6,13]. Pramanik *et al*. (2020) [13] observed significantly higher average bulb weight and total bulb yield per plot. This might be due to the active role of micronutrients in the plant metabolic process starting from cell wall development to respiration, photosynthesis, chlorophyll formation, enzyme activity and nitrogen fixation.

3.2 BULB YIELD (Q/HA)

Application of micronutrients *i.e.,*treatment T_2- foliar spray of ready-mix containing (Zn, Mg, Fe, Mn, Cu, Mo and Bo 0.25%) (Table 1) had highest bulb yield (198, 265 & 300 q/ha) whereas, in T_1 (without spray of micronutrients) bulb yield (180, 245 & 275q/ha) during 2021-22, 2022-23 and 2023-24, respectively. It might be due the crucial role of micronutrients in strengthening the crop.

3.3 ECONOMICS

It is revealed from (Table 2) that maximum net return (₹ 104400, 323000& 98000/ ha) and benefit cost ratio (2.93, 4.19 & 2.89) were recorded in the treatment T_2- foliar spray of ready-mix containing (Zn, Mg, Fe, Mn, Cu, Mo and Bo 0.25%) (Table 2) whereas, T_1 (without spray of micronutrients) net return were (₹ 91000, 292000 & 86500/ ha) and BC ratio (2.71, 3.92 & 2.69) during 2021-22, 2022-23 and 2023-24, respectively. The present results corroborate the findings of Smiriti *et al.* (2002) [17] for boron while Nasreen *et al.* (2009) [12] and Pramanik *et. al.,* (2020) [13] for zinc as a source of micronutrients towards increased benefit cost ratio in onion production.

Table 1: Impact of micronutrients foliar spray on Bulb weight and bulb yield of onion.

	Bulb weight (g)	Bulb Yield (q/ha)	Increase (%)
Rabi 2021-22			
T_1- FP (No Spray)	45.30	180	-
T_2-Foliar application of Micronutrient	54.48	198	8.33
Rabi 2022-23			
T_1- FP (No Spray)	47.50	245	-
T_2-Foliar application of Micronutrient	55.60	265	8.1
Rabi 2023-24			
T_1- FP (No Spray)	48.40	275	-
T_2-Foliar application of Micronutrient	57.20	300	9.09

Increase in production was found 8.33 %, 8.1 % and 9.09 % during 2021-22, 2022-23 and 2023-24, respectively in treatment T_2 as compared to treatment T_1. Dake *et al*. (2011) [5] and Abd EI- Samad *et al.* (2011) [2], they reported that growth parameters of onion plant were positively affected by foliar application of micronutrients. In addition, zinc and boron play an essential role in improving plant growth, through the biosynthesis of endogenous hormones, which is responsible for promotion of plant growth. Therefore, the use of micronutrient application to be increases the production, improve economics and beneficial for onion cultivation.

Table 2: Impact of micronutrients foliar spray on economics of onion.

	Cost of cultivation (Rs/ha)	Gross income (Rs/ha)	Net income (Rs./ha)	B:C ratio	Sale price (Rs./q)
Rabi 2021-22					
T_1- FP (No Spray)	53000	144000	91000	2.71	800
T_2-Foliar application of Micronutrient	54000	158400	104400	2.93	
Rabi 2022-23					
T_1- FP (No Spray)	100100	392000	292000	3.92	1600
T_2-Foliar application of Micronutrient	101000	424000	323000	4.19	
Rabi 2023-24					
T_1- FP (No Spray)	51000	137500	86500	2.69	500
T_2-Foliar application of Micronutrient	52000	150000	98000	2.89	

IV. CONCLUSION

From the above three consecutive year of research, it is concluded that application of ready-mix containing (Zn, Mg, Fe, Mn, Cu, Mo and Bo 0.25%) @ 2.5 ml/ litre at 30 and 45 days after transplanting of onion seedlings was found better for higher yield and parameters of economics of onion as over to control treatment. Hence may be recommended that application of ready-mix consists of all essential micronutrients gives better vegetative growth in term of growth, bulb weight and bulb production along with higher BC ratio as compared to control treatment.

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Analysis of soil fertilization practices by market gardeners and their perception of the use of compost based on mango residues in the commune of Korhogo, northern Ivory Coast

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***Abstract*— *Market gardening is a key source of income and food security for households in Korhogo. With urban expansion, pressure on soils has increased, leading to declining fertility and threatening production sustainability. This study aimed to assess current fertilization practices and explore the potential of mango residue compost as a local alternative. A survey of 72 producers across six urban and peri-urban sites—mostly women—focused on crops, fertilizer types, application methods, and constraints. Results show that 93% use chemical fertilizers, mainly NPK (88%), while only 28% use organic inputs and less than 10% use compost. Microdose application is common, helping reduce leaching. Major constraints include poor soils, irregular rainfall, and pests. Despite limited adoption, producers expressed strong interest in mango compost due to its local availability. Barriers include lack of information, technical skills, and equipment. These findings highlight the need for simple, adapted solutions. Developing a local composting system based on mango residues could improve soil health and reduce reliance on chemical inputs.*

***Keywords*— Investigation, Fertilizers, Soil fertility, Market gardeners, Korhogo, Ivory Coast**

I. INTRODUCTION

Agriculture is a major economic sector worldwide, employing more than 40% of the working population, and up to 52% of this population, generally, in Africa [1]; [2]. In Côte d'Ivoire, as in many sub-Saharan African countries, it plays a key role in socio-economic development. Among its many branches, urban and peri-urban market gardening plays an essential role in food supply in Africa [3]. The department of Korhogo is distinguished by its flourishing market gardening activity, driven by pedoclimatic conditions favorable to the cultivation of several vegetables, such as eggplant, chili pepper, okra, onion and tomato [4].

Intra-urban market gardening represents both an economic survival strategy for vulnerable urban populations and an expression of their socio-cultural identities through agricultural practices. Settled in precarious spaces, such as lowlands, wastelands and dam areas, producers demonstrate resilience in the face of urban pressure and land uncertainties [5]. Market gardening in Korhogo is developing mainly in urban lowlands, due to their accessibility, water availability and increasing land pressure linked to the expansion of the city. [6], thus leading to the development of urban and peri-urban agriculture [7]. However, this intensification is not without consequences: like the trends observed in other parts of Côte d'Ivoire [8], where soils are subject to continuous exploitation, which leads to their degradation and the progressive decline of their fertility [7]. This situation is even more accentuated in Korhogo, where the exploited soils are, mainly, sandy, poor in organic matter and facilitate the leaching of mineral elements, which pushes market gardeners to resort to frequent applications of chemical fertilizers [9]. In this context, sustainable soil fertility management has become a crucial issue for the sustainability of market gardening production systems in the region. This study, whose general objective is part of an approach to analyzing local agricultural practices, aims to introduce the use of compost from mango residues as an alternative solution to improve soil fertility by studying the diversity of fertilizer types and the variability of doses applied under market gardeners in the city of Korhogo. Through a survey conducted among market gardeners in Korhogo, it will examine several essential aspects: the different types of fertilizers used (i), the constraints linked to market gardening production (ii), as well as the perception of producers regarding the use of rejected mangoes for the manufacture of compost (iii).

II. MATERIALS AND METHODS

Study area

The study was conducted in the city of Korhogo, located in the north of Côte d'Ivoire, with geographical coordinates of 9° 26' north longitude and 5° 38' west latitude. Its climate, of the Sudanese type, is characterized by the alternation of two seasons: from October to April, a long dry season, followed by the rainy season, marked by two peaks of water precipitation in June and September. Annual precipitation varies between 1100 and 1600 mm of water, while sunshine reaches approximately 2600 hours per year. Local climatic conditions include average temperatures, ranging from 24 to 33 °C, as well as an average monthly humidity of 20%. The natural vegetation is dominated by savannah, which can be sometimes grassy and sometimes wooded. The soils of the region are of the tropical ferruginous type, formed on granite. These soils, more or less leached, have a low water retention capacity, a very acid pH (4.7) and low nutrient content, which considerably limits their fertility and agricultural potential [10]. The study sites are distributed in several areas in the city of Korhogo: in the south (Logokaha, Téguéré), in the southeast (Kassirimé), in the northwest (Cocody) and in the west (Haoussabougou and Koko) (figure 1).

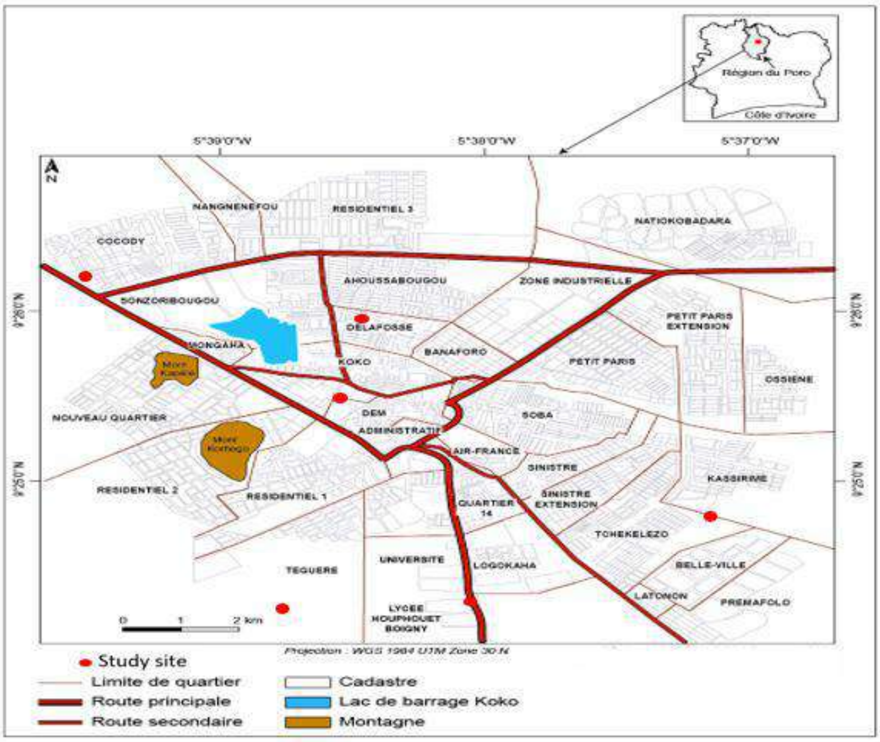

Fig.1: Presentation of study sites

Plant material

The survey focused on producers of different market garden crops, representative of local agricultural practices in the study area. The main species cultivated by these market gardeners were tomato (*Solanum lycopersicum*), eggplant (*Solanum melongena*), cabbage (*Brassica oleracea*), okra (*Abelmoschus esculentus*), chili pepper (*Capsicum spp.*) and lettuce (*Lactuca sativa*). *These* market garden crops play an essential role in urban and peri-urban agricultural production in the city of Korhogo. They are particularly grown in the lowlands of the city, especially around Lake Koko and on undeveloped land, due to the strong land pressure caused by the strong population expansion [9]. Women (up to 98% of producers) mainly carry out this activity.

Technical equipment

The study relied on survey forms, including both closed and open-ended questionnaires, as well as semi-structured interview guides. The questionnaires allowed for the collection of quantitative data on the practices and perceptions of market gardeners, while the semi-structured interviews provided the opportunity to explore certain aspects in more depth and to collect detailed qualitative information. The questionnaires were submitted to market gardeners in the city of Korhogo.

Methods

This study used a methodological approach, combining a field survey, with the use of guides and questionnaires, as well as semi-structured interviews. The survey took place from July 22 to 25, 2024, with 72 market gardeners, spread across six districts of the city of Korhogo: Cocody, Haoussabougou, Koko, Kassirimé, Téguéré and Logokaha. A sample of 12 market gardeners per district was selected, in order to ensure representativeness of the different production sites. Each producer was questioned individually about his cultivation practices directly on his plot, in order to ensure the existence of his plot. The interview addressed several essential aspects, linked to market gardening practices. These were:

- fertilization which concerns the different market garden crops grown, the types of fertilizers used (mineral or organic), the justifications for the choice of these fertilizers, their availability and their methods of application, the quantities or doses applied and the periods and frequencies of application of the fertilizers.
- The constraints focused on the main difficulties encountered by producers, in particular, soil fertility and the destruction of crops due to pests and diseases, as well as the lack of rain.
- Composting of mango residues revolved around the level of knowledge of producers about making compost from abandoned mangoes, as well as their perception of using compost as an alternative to chemical fertilizers.

Statistical analyses

Sphinx Plus software was used for the design and entry of questionnaires. The quantitative data collected were analyzed using SPSS version 26 software, while the qualitative data, from the semi-structured interviews, were processed using a qualitative analysis method. Microsoft Excel software was used for the design of tables and figures.

III. RESULTS

Types of fertilizers used

The study identified the different types of fertilizers used by market gardeners in the six localities (Figure 2). Analysis of the results revealed a clear preference among market gardeners for chemical fertilizers over organic fertilizers, with usage rates varying between 58.81% and 87.15%, depending on the locality. Indeed, the locality of Haoussabougou showed the highest rate (87.15 %), followed by Logokaha, where the use of chemical fertilizers exceeded 82.12%. However, despite this predominance, Kassirimé and Cocody showed slightly lower proportions compared to other areas, respectively, 58.81% and 67.03%.

Regarding organic fertilizers, Kassirimé stood out, with the highest proportion (41.19%). Conversely, Haoussabougou, which showed the highest use of chemical fertilizers, also presented the lowest proportion of use of organic fertilizers (12.85%), as did Logokaha (17.88%), where their use remained very minimal.

Chemical fertilizers

Different types of chemical fertilizers encountered

The analysis revealed that the most commonly used types of fertilizers by market gardeners are NPK, urea and foliar fertilizers (Figure 3). NPK fertilizer was largely dominant, with an average usage rate of 74.90 %, compared to 4.10% for urea and 21 % for foliar fertilizer, and this in almost all localities. Some areas showed marked trends in the use of chemical fertilizers. Cocody, Kassirimé and Logokaha recorded the highest rates of NPK use, reaching 83%. Urea, on the other hand, is used with a very low proportion in all areas, with particularly low rates in Cocody, Kassirimé, Téguéré and Logokaha. However, Haoussabougou and Koko had slightly higher rates (8.30%), although they remained below the average. Foliar fertilizer, used more than urea, varied more, depending on the locality. Koko recorded the highest rate (33.30%), followed by Haoussabougou (16.70%) and Cocody (25%). In contrast, Kassirimé, Téguéré and Logokaha had the lowest rates of use (17%).

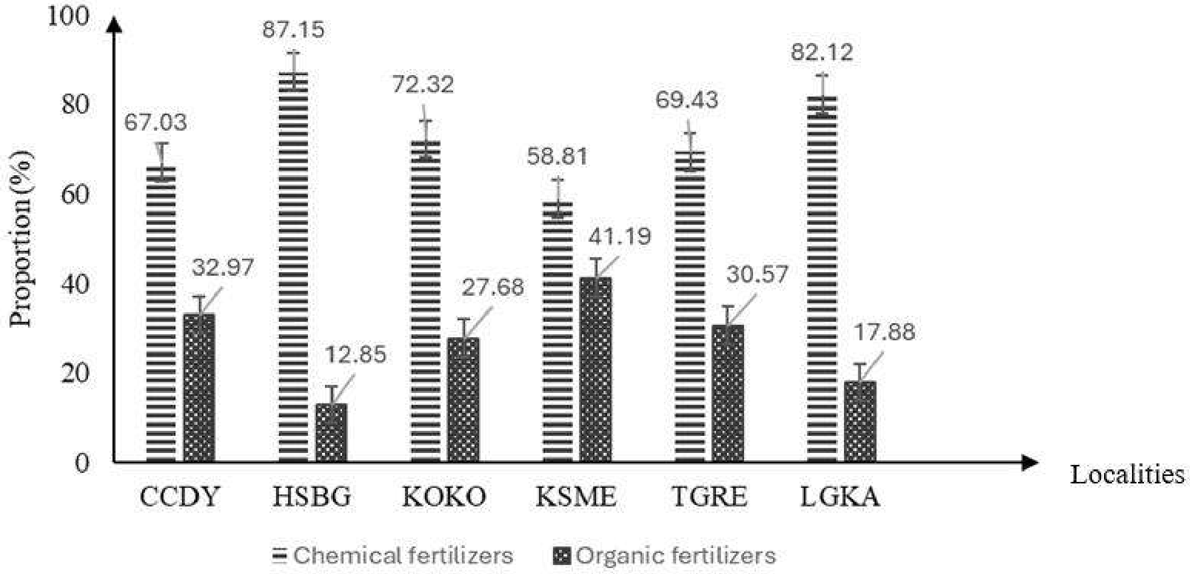

Fig.2: Different types of fertilizers used by market gardeners

CCDY: Cocody; HSBG: Haoussabougou; Koko; KSME: Kassirimé; TGRE: Téguéré; LGKA: Logokaha

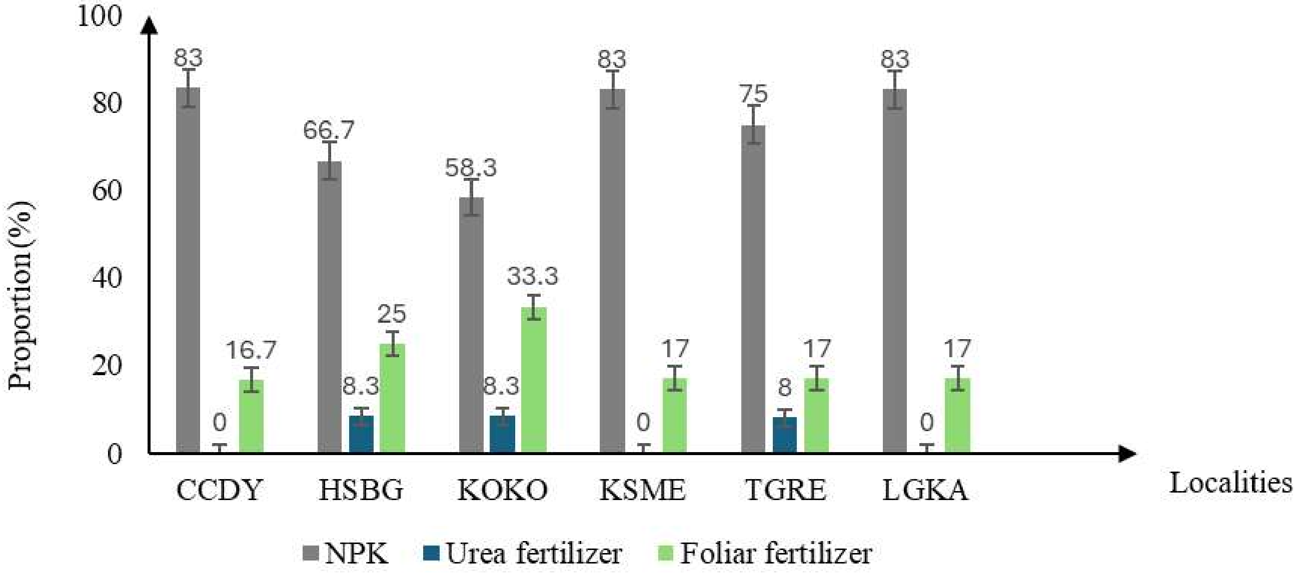

Fig.3: Different chemical fertilizers used in market gardening areas

CCDY: Cocody; HSBG: Haoussabougou; Koko; KSME: Kassirimé; TGRE: Téguéré; LGKA: Logokaha

Methods of spreading chemical fertilizers

The market gardeners surveyed apply different methods of spreading chemical fertilizers, including microdose, broadcast spreading, and side spreading (Figure 4). However, the study revealed that only the first two are actually used in the field. Microdose spreading is the dominant technique, with an average use of 75% across all market gardening areas surveyed. The localities of Téguéré and Koko recorded the highest rates, reaching 91.70% and 83.30% respectively. On the other hand, broadcast spreading remained marginal, with an average of 25%, although some areas such as Haoussabougou (41.70%) and Kassirimé (33.30%) stood out for relatively higher adoption. Conversely, the lowest proportions for this method were observed in Koko (16.70%) and Téguéré (8.30%). As for lateral spreading, it was not practiced in any of the areas studied (0%).

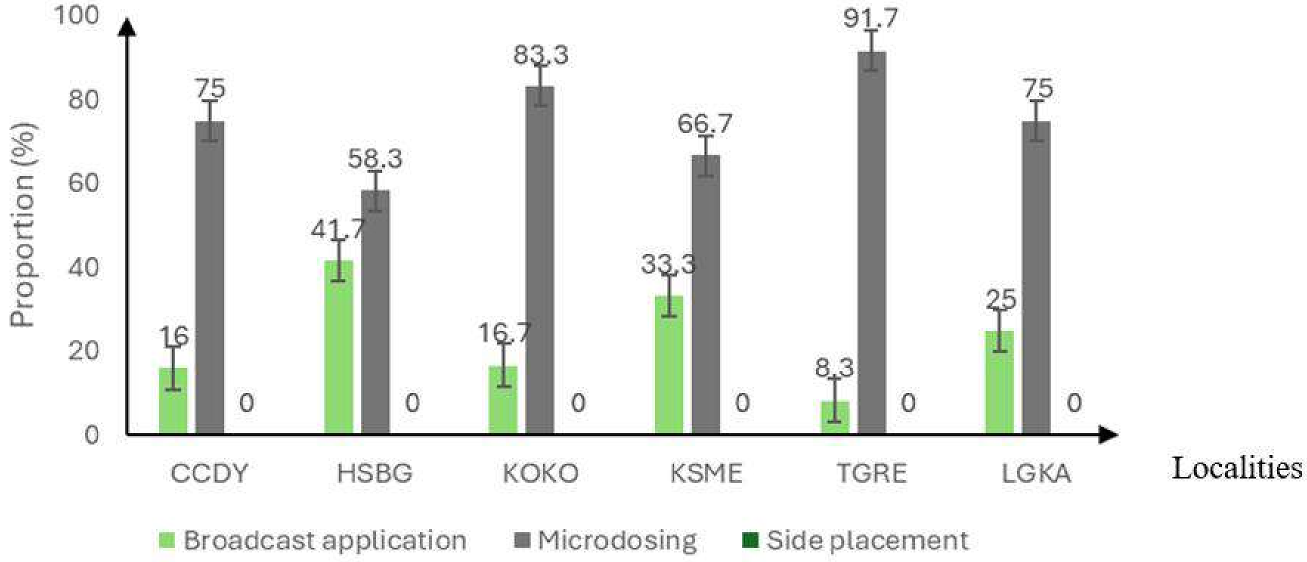

Fig.4: Methods of spreading chemical fertilizers according to the zones

CCDY: Cocody; HSBG: Haoussabougou; Koko; KSME: Kassirimé; TGRE: Téguéré; LGKA: Logokaha

Periods of application of chemical fertilizers

The periods of application of chemical fertilizers after transplanting are mainly divided into two key moments: two weeks (02SAR) and three weeks (03SAR) after transplanting as detailed in Table 1. Analysis of the results revealed that the majority of market gardeners (69.40%**)** applied chemical fertilizers at 02SAR. This practice was largely predominant in most localities. The market gardening areas of Téguéré and Logokaha recorded the highest rates of application at 02SAR (91.70% each), followed by Koko (74.60%). Furthermore, Haoussabougou and Kassirimé also showed a strong preference for this method, with a rate of 58.30% in both localities. However, application at 03SAR was generally lower, although it varied depending on the areas studied. Indeed, Cocody was an exception, being the only locality where application at 03SAR (58.30%) exceeded that at 02SAR (41.70 %). In addition, Haoussabougou and Kassirimé showed average application rates at 03SAR (41.70% each), while Koko showed a relatively low rate (25.40%). On the other hand, the areas of Téguéré and Logokaha showed very low application rates at 03SAR (8.30% each).

Table 1: Periods of application of chemical fertilizers according to the zones

	Proportion (%)						
Period	CCDY	HSBG	KOKO	KSME	TGRE	LGKA	Average
02SAR	41.7	58.3	74.6	58.3	91.7	91.7	69.4
03SAR	58.3	41.7	25.4	41.7	8.3	8.3	30.6

CCDY: Cocody; HSBG: Haoussabougou; Koko; KSME: Kassirimé; TGRE: Téguéré; LGKA: Logokaha, 02SAR: two weeks after transplanting; 03SAR: three weeks after transplanting

Doses of NPK provided by market gardeners

The different doses of NPK applied by market gardeners in their farms, according to the localities studied, is illustrated in Figure 5. The analysis revealed that the dose of 40 g/plant was more frequently applied, representing 55.32% of applications, compared to 44.67% for the dose of 20 g/plant. This preference for 40 g/plant was particularly marked in Koko, Kassirimé, Téguéré and Logokaha, where its use exceeded that of 20 g/plant. In the locality of Kassirimé , the dose of 40 g/plant was mainly applied by market gardeners (75%), compared to only 25% who opted for the dose of 20 g/plant. However, some localities, such as Cocody and Haoussabougou, were an exception to this trend and recorded a preference for the 20 g/plant dose. This dose was used predominantly with 58.30% of cases in both areas. Thus, this analysis highlights an overall preference for the 40 g/plant dose although some areas, notably Cocody and Haoussabougou, have favored the application of 20 g/plant.

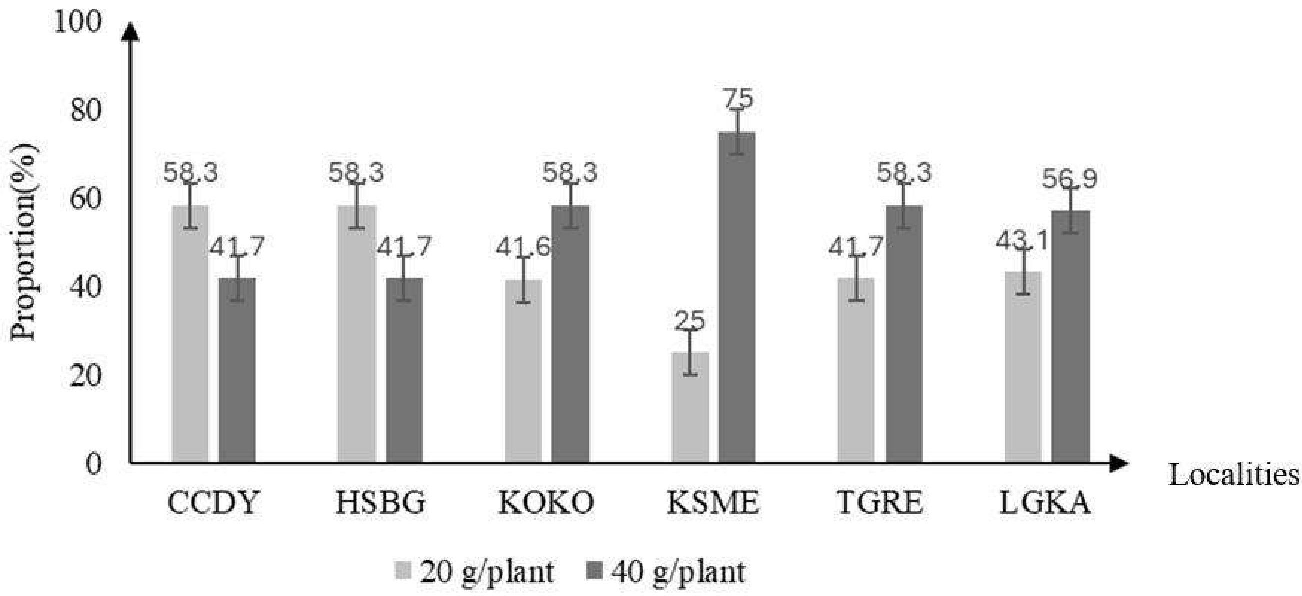

Fig.5: Doses of NPK applied per pocket depending on the areas

CCDY: Cocody; HSBG: Haoussabougou; Koko; KSME: Kassirimé; TGRE: Téguéré; LGKA: Logokaha

NPK Fertilizer Application Frequencies

Regarding the frequency of application of NPK fertilizer, two main methods were noted among market gardeners, namely, a single application and two applications per crop cycle, as shown in Table 2. The results of the analysis indicated that the practice of making two applications of NPK fertilizer was more frequent, with an average rate of 55.32%, compared to 44.68% for the single application. However, differences were observed between localities. In Kassirimé , the frequency of applying NPK fertilizer twice out of the two applications was largely dominant, reaching a rate of 83.30%, compared to only 16.70% of market gardeners who opted for a single application. Furthermore, market gardeners in the localities of Téguéré and Logokaha also favored a frequency of two applications of NPK fertilizer, with respective rates of 58.30% and 56.90%. Conversely, market gardeners in the Cocody and Haoussabougou areas mostly opted for a single application of NPK fertilizer, with a rate of 58.30%, while those in the Koko area showed a more balanced distribution between the two practices. This analysis reveals a general trend in favor of double application of NPK fertilizer per crop cycle.

Table 2: NPK application frequencies during the crop cycle

	Proportion (%)					
Frequency	CCDY	HSBG	KOKO	KSME	TGRE	LGKA
01 times	58.3	58.3	50	16.7	41.7	43.1
02 times	41.7	41.7	50	83.3	58.3	56.9

CCDY: Cocody; HSBG: Haoussabougou; Koko; KSME: Kassirimé; TGRE: Téguéré; LGKA: Logokaha

Organic fertilizers

Different types of organic fertilizers encountered

The different types of organic fertilizers encountered in the market gardening areas studied are cow dung, poultry manure and compost, as presented in Table 3. The survey results revealed a clear preference among market gardeners for cow dung and poultry manure, with particularly high adoption rates. On the other hand, they highlighted a low use of compost. In the localities of Cocody, Koko, Téguéré and Logokaha, all the market gardeners surveyed (100%) indicated that they used cow dung exclusively as organic fertilizer. In Haoussabougou and Kassirimé, the rates were slightly lower, but remained very high, reaching 83.3% and 86% respectively.

Regarding poultry manure, the results highlighted a high adoption, particularly in Kassirimé and Téguéré, where all the market gardeners surveyed (100%) reported using it. The other areas also recorded high rates, varying between 88% and 96.5%. Conversely, compost is very little used. No market gardener uses it in Cocody, Haoussabougou and Téguéré. In Koko, Kassirimé and Logokaha, its use remained moderate, with respective rates of 16.7%, 12% and 18%. This analysis thus confirms that cow dung and poultry manure are the main sources of organic fertilizers used by market gardeners in the areas studied.

Table 3: Different types of organic fertilizers used by market gardeners

	Proportion (%)					
Organic fertilizers	CCDY	HSBG	KOKO	KSME	TGRE	LGKA
Cow dung	100	83.3	100	86	100	100
Compost	0	0	16.7	12	0	18
Chicken droppings	96.5	91.7	88	100	100	91.7

CCDY: Cocody; HSBG: Haoussabougou; Koko; KSME: Kassirimé; TGRE: Téguéré; LGKA: Logokaha

Methods of spreading organic fertilizers

As part of the survey, the following three spreading methods were submitted to the market gardeners for their assessment: microdose, broadcast and lateral (Table 4). The results of the survey indicated that microdose spreading is the most widely adopted in the majority of localities. It is particularly dominant in Cocody and Téguéré, where it represents 75% of the practices recorded. In Koko and Kassirimé, this method also remained in the majority, with an identical rate of 58.3%. Even in the locality where it is least used, Haoussabougou, it still reaches 16.7%. Broadcast spreading, for its part, presents a marked variability depending on the locality. It is in the majority in Haoussabougou (83.3%), thus constituting an exception compared to other areas where microdose predominates. In Koko (41.7%) and Kassirimé (41.5%), this method occupies an important place, representing almost half of the practices observed, although it is overtaken by microdose spreading. In Cocody and Téguéré, it remains less frequent (25%), while in Logokaha, its use is equivalent to that of microdose, suggesting a balanced distribution between the two methods. No occurrence of lateral spreading was recorded in the areas surveyed (0%).

Table 4: Different methods of spreading organic fertilizers by market gardeners

	Proportion (%)					
Spreading methods	CCDY	HSBG	KOKO	KSME	TGRE	LGKA
By volley	25	83.3	41.7	41.5	25	50
By microdose	75	16.7	58.3	58.3	75	50
Lateral	0	0	0	0	0	0

CCDY: Cocody; HSBG: Haoussabougou; Koko; KSME: Kassirimé; TGRE: Téguéré; LGKA: Logokaha

Periods of application of organic fertilizers

The study showed that organic fertilizers are generally applied to market garden crops one to two weeks before transplanting (Table 5). Analysis of the results indicated that the majority of market gardeners apply fertilizers one week before transplanting (01 SAVR), in all the areas studied. The proportions associated with this period vary from 66.7% in Kassirimé to 91.7% in Koko, Téguéré and Logokaha. On the other hand, application two weeks before transplanting (02 SAVR) is infrequent, or even absent in several areas. It is completely non-existent (0%) in Cocody, Koko, Kassirimé and Téguéré. It appears only marginally in Haoussabougou (8.3%) and reaches its highest level in Logokaha (17.7%). However, even in this latter locality, the practice of contribution to 01 SAVR remains very largely in the majority (91.7%), relegating 02 SAVR to a residual position.

Table 5: Period of application of organic fertilizers

	Proportion (%)					
Periods	CCDY	HSBG	KOKO	KSME	TGRE	LGKA
01 SAVR	83.3	75	91.7	66.7	91.7	91.7
02 SAVR	0	8.3	0	0	0	17.7

CCDY: Cocody; HSBG: Haoussabougou; Koko; KSME: Kassirimé; TGRE: Téguéré; LGKA: Logokaha;

01 AVR: one week before transplanting; 02 SAVR: two weeks before transplanting

Quantities of organic fertilizers used by producers

The quantities of organic fertilizers applied by market gardeners vary according to the sites, with three main doses identified, namely 200 g, 300 g and 400 g per plant (Figure 6). Analysis of the results showed a clear predominance of the dose of 400 g/plant, widely adopted in most of the localities surveyed. It is used by 100% of producers in Cocody and Haoussabougou, by 91.7% in Koko, 83.3% in Kassirimé and 75% in Logokaha. On the other hand, doses of 200 g and 300 g/plant are rarely used. The dose of 200 g/plant was only observed in locality of Téguéré, where it reached 83.3%, while the dose of 300 g/plant was recorded only in Koko, with a rate of 16.7%. These results highlight a strong preference among producers for using 400 g/plant as a reference dose for the application of organic fertilizers under vegetable crops.

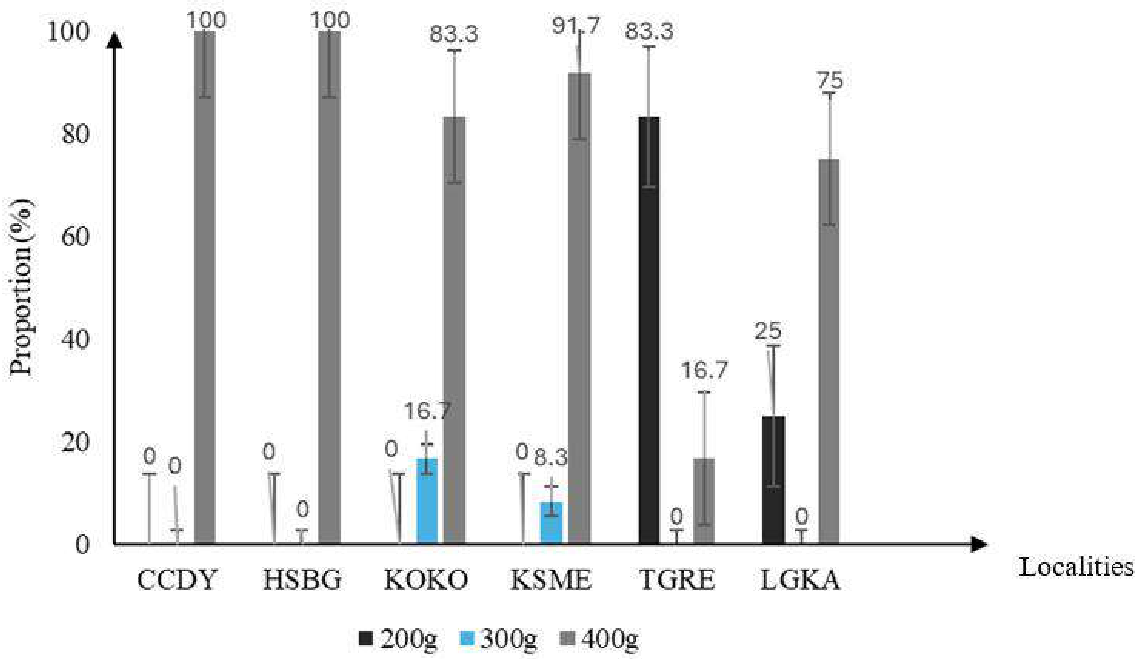

Fig.6: Quantities of organic fertilizers provided by market gardeners

CCDY: Cocody; HSBG: Haoussabougou; Koko; KSME: Kassirimé; TGRE: Téguéré; LGKA: Logokaha

Constraints encountered by market gardeners

The survey carried out in the six localities concerned made it possible to identify the main difficulties encountered by market gardeners, namely poor soils, lack of rain and crop destruction (Figure 7). Analysis of the responses showed that poor soils are the most frequently mentioned constraint, with a citation rate of 100% in Cocody, 97% in Haoussabougou, Kassirimé and Logokaha, and 94.6% in Téguéré. Although slightly lower, the proportion observed in Koko remained high, reaching 88.4%. Lack of rain is the second most mentioned constraint, but with more variable citation levels depending on the locality. It is particularly high in Cocody (93%), Haoussabougou (83.3%), Koko (83.3%) and Kassirimé (83.3%). In Téguéré, its proportion is 78% and in Logokaha, it reaches 91.7%. The least frequently mentioned constraint was the destruction of crops. It was cited by 93% of producers in Cocody, 87% in Haoussabougou, 75% in Koko and Kassirimé, 66.7% in Logokaha, and only 65% in Téguéré.

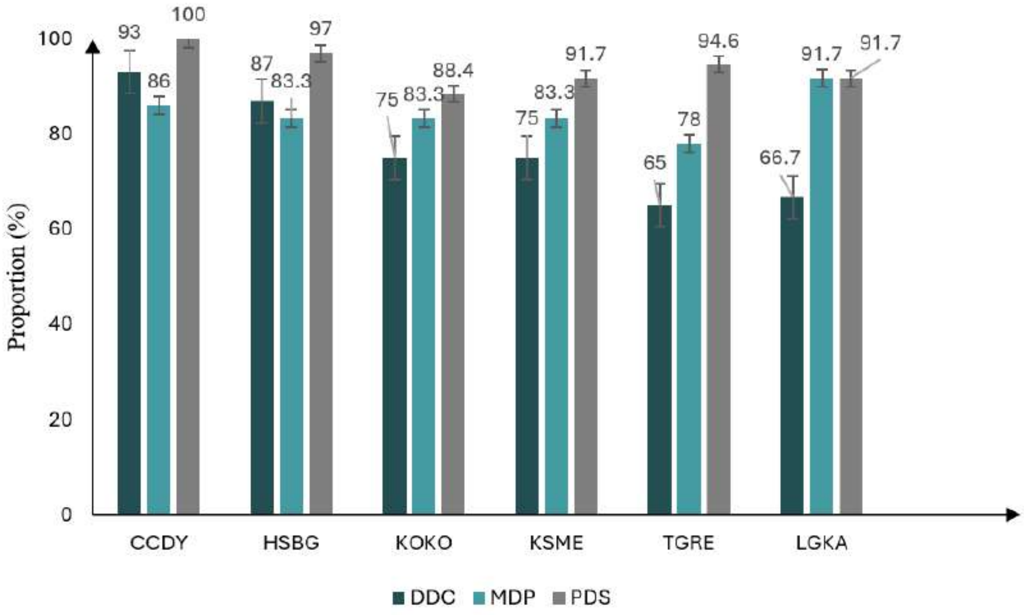

Fig.7: Evaluation of constraints encountered by market gardeners depending on the location

CCDY: Cocody; HSBG: Haoussabougou; Koko; KSME: Kassirimé; TGRE: Téguéré; LGKA: Logokaha; DDC: Destruction of crops; MDP: Lack of rain; PDS: Soil poverty

Market gardeners' perceptions of the use of compost from mango residues

Market gardeners' perception of the use of compost from mango waste, as well as their ability to use it, is expressed as a percentage (%) in Table 6. Analysis of the results indicated that none of the market gardeners surveyed, regardless of location, currently uses this type of compost. However, all those surveyed reported being able to use it. This situation revealed a general lack of information on the possibilities of recovering mango waste through composting, although producers expressed a favorable disposition to its use.

Table 6: Peasant perception of market gardeners on the use of compost from mango residues

		Proportion (%)					
	Perception	CCDY	HSBG	KOKO	KSME	TGRE	LGKA
Use	YES	0	0	0	0	0	0
	NO	100	100	100	100	100	100
Fit for use	YES	100	100	100	100	100	100
	NO	0	0	0	0	0	0

CCDY: Cocody; HSBG: Haoussabougou; Koko; KSME: Kassirimé; TGRE: Téguéré; LGKA: Logokaha

IV. DISCUSSION

An analysis of agricultural practices in Korhogo revealed a strong preference among market gardeners for chemical fertilizers when fertilizing their various crops. The survey results showed that approximately 60% of market gardeners used chemical fertilizers, compared to less than 30% for organic fertilizers. These results could be explained by the widespread availability of chemical fertilizers on local markets, their ease of use, and their immediate effect on crop growth and yields. This observed trend is consistent with those of [11] and [12], who pointed out that the intensive use of mineral fertilizers by producers is motivated by the search for rapid and high yields. Indeed, organic fertilizers are mainly underused due to their limited availability, lack of practical knowledge among producers, slow release of their nutrients and the large quantities required to achieve the desired effects. These causes were also supported by [13] and [14]. These authors indicated that a lack of awareness about organic fertilizers leads to their reduced use and a lack of knowledge about their real effectiveness. Thus, the use of chemical fertilizers seems to be the priority, due to their immediate effects, while organic fertilizers are very little used, for many reasons.

In order to optimize fertilizer use, market gardeners have generally adopted the application of fertilizers by pocket, localized application, or microdose. Lateral and broadcast applications are only used irregularly in different areas. These results are justified by the fact that microdose applications are more economical, due to the reduction of nutrient losses and the high availability of these fertilizers for the benefit of the root system. This shows that producers choose the fertilizer application methods best suited to their limited resources and different types of crops. These results corroborate those of several studies conducted in sub-Saharan Africa. The work, conducted by [15] Fatondji *et al.* (2024), showed that microdose applications could improve fertilizer use efficiency by 40 to 50% compared to broadcast spreading. Similarly, studies by [16], in Senegal, and [17] in Ethiopia also showed that micro-dose fertilizer application could achieve higher yields than conventional broadcast and band application methods. This application method would reduce application quantities and investment costs, and improve fertilizer profitability and efficiency, particularly for smallholder farmers with limited resources.

NPK has been widely recognized as the most widely used chemical fertilizer in agriculture, due to its ability to improve soil fertility and boost yields. Studies, such as those by [18], from [19] and [20], confirm its effectiveness in various agro-ecological contexts. For these authors, the application of 100% NPK, in certain contexts, generates higher yields than those obtained with partial or combined dosages. The majority of the market gardeners surveyed apply chemical fertilizers two weeks after transplanting their market garden, because this method would be encouraged by research and agricultural cooperatives to improve fertilization efficiency and optimize crop production. These results corroborate those of [21], who showed that the application of nitrogen fertilizers, just before transplanting, optimizes their absorption, and limits losses. The effectiveness of fertilizers varied depending on the dose applied and the varieties grown. The dose of 40 g of NPK per plant was the most frequently mentioned. This dose was considered the most effective in this low fertility area. The mineral elements made available to crops were the most sufficient to cover their nutrient needs, in order to ensure good production. Works, like those of [22], showed that moderate doses of NPK, around 30 to 40 g per plant, and by localized application, improve the effectiveness of the fertilizer, in areas with low fertility, and the productivity of rice. Regarding the frequency of application, market gardeners mainly practiced split applications in two times per cycle. Split applications of mineral fertilizers, by the majority of market gardeners, would be justified by the coverage of nutrient needs at any time during the cycle of the crops grown. These results were confirmed by the work of [7]. These authors showed that for better optimization of the fertilizers to be applied, market gardeners adjust both the number of applications and the fertilizer doses according to the type of soil and the recommendations received. Therefore, for better crop productivity and a reduction in fertilizer losses, the doses, number of applications and timing of fertilizer use are rules to be respected within the framework of rational fertilization.

The survey also revealed that market gardeners largely prefer to use organic fertilizers of animal origin, such as cow dung and poultry droppings, to the detriment of composts from plant materials. This preference could be explained by the easy access to the droppings of these animals, which is due to the predominance of livestock farming in the survey region and the ease of decomposition or composting of animal organic matter . These results are supported by the work of [23] who showed that producers use a wide variety of animal manures for the amendment of different crops , due to their accessibility , high fertilizing value , immediate effect and ease of use . Similarly, [24] indicated that animal droppings are a high source of major and secondary mineral elements, namely, N, P, K, Ca, Mg and Cl.

The study also showed that the market gardeners surveyed mostly apply compost a week before transplanting the seedlings. This practice can be explained by the fact that the organic matter has already been mineralized, and its nutrients will be immediately usable when the plants are installed. In the same vein, [25] showed that organic fertilizers with a low C/N ratio released nutrients quickly, making them easier for farmers to use. According to [26], market gardeners in northern Côte d'Ivoire adopt empirical soil fertility management practices based on personal experience. Indeed, according to these authors, the addition of organic fertilizers, some time before planting crops, is considered an effective and reassuring compromise for producers.

Our results showed that most of the market gardeners surveyed used a dose of 400 g of organic fertilizer per plant, while doses of 200 and 300 g were not very widespread. This preference for high doses could be explained by farmers' concern to provide a sufficient quantity of nutrients to crops, in the absence of soil analyses. [27], [28] and [29] highlighted the positive effects of high organic fertilizer application under vegetable crops in different growing regions. These high inputs of organic fertilizers contribute not only to improving crop yields and the quality of production, but also to sustainably improving the physicochemical properties of the soil.

The survey indicated that the main constraint for market gardeners is soil depletion, aggravated by a rainfall deficit. This situation is said to be the result of land pressure, which is very imminent and recurrent in the northern regions of the country. This soil depletion is also due to overexploitation of arable land, uncontrolled urbanization, prolonged use of chemical fertilizers and inadequate cultivation practices [30], [31].

None of the producers surveyed uses compost from mango waste. This situation could be explained by several reasons, namely, the lack of information on the use of mango residues for composting, the difficulty of mineralizing mango waste, the lack of information on the chemical and mineral compositions of mango residues by producers and the difficulty of acquiring mango waste. For some authors, the limited adoption of mango residues, as organic fertilizer, is explained by a lack of technical training of producers in composting and equipment adapted to composting and the failure to restructure the sector to assess losses [32], [33]. Indeed, huge quantities of mangoes are lost by the sector and huge waste is rejected each year by processing units, but also by the majority of producers and retailers [33]. In a context of transition towards more sustainable agricultural practices, composting mango residues would represent a local and economic solution for producers, the sector and, above all, for market gardeners.

V. CONCLUSION

The study, conducted in Korhogo, made it possible to take stock of the fertilization practices used by market gardeners, while evaluating the prospects for introducing compost from mango residues, as a local and sustainable solution.The results revealed a heavy reliance on chemical fertilizers, especially NPK, for its availability and immediate effectiveness. Organic fertilizers remain underused, often due to their slower effect, and compost is largely unknown. Microdosing is the most common application method. It allows for optimal fertilizer use, limiting leaching losses, while ensuring good yields. During the survey, market gardeners also highlighted several major constraints affecting their activity and the sustainability of production systems. These are soil depletion, climate variability, pest pressure, and a lack of technical support. Despite these challenges, discussions showed a growing interest in mango compost, particularly because these residues are locally available in large quantities in the city of Korhogo. However, its adoption remains limited, hampered by a lack of information on its use as organic matter for composting. Thus, future research is needed to develop a composting process accessible to all, in order to facilitate its integration into market gardeners' agricultural practices. This approach will help restore soil fertility, contribute to reducing dependence on chemical fertilizers and consolidate the resilience of market gardening systems.

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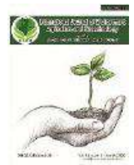

Comparative effects of organic and inorganic fertilizers on soil organic carbon under sub-humid southern plain and Aravalli hills of Rajasthan

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Abstract— *A field experiment was conducted during rabi 2023–24 and 2024–25 at the Instructional Farm, Rajasthan College of Agriculture, Udaipur, to evaluate the comparative effects of long-term organic and inorganic fertilization on soil organic carbon (SOC) under a maize–wheat cropping sequence. The experiment was laid out in a randomized block design with 12 nutrient management treatments, comprising sole chemical fertilizers, organic manures and their integrated combinations. The results revealed that SOC content was significantly enhanced under organic and integrated nutrient management practices compared to sole chemical fertilization and unfertilized control. Application of FYM @ 20 t ha⁻¹ (T_8) recorded the highest SOC values (0.985–0.987%), showing nearly an 86% increase over control (0.530%), followed by NPK + FYM 10 t ha⁻¹ (T_7: 0.942%) and FYM 10 t + 100% NPK (T_6: 0.921%). Balanced fertilization with micronutrients and biofertilizers resulted in moderate improvements in SOC, whereas imbalanced fertilization treatments such as 100% N and 100% NP showed limited effectiveness. Pooled analysis across years confirmed that continuous application of FYM, either alone or in combination with NPK, was most effective in sustaining and building soil organic carbon. The study highlights the critical role of organic and integrated nutrient management in enhancing soil carbon stocks, thereby improving soil health and sustainability of wheat-based cropping systems in the sub-humid southern plain and Aravalli hills of Rajasthan.*

Keywords— ***Soil organic carbon, integrated nutrient management, farmyard manure, soil health, sustainable agriculture***

I. INTRODUCTION

Soil organic carbon (SOC) is a fundamental indicator of soil health and plays a pivotal role in regulating nutrient availability, soil structure, water retention and biological activity, thereby directly influencing crop productivity and long-term sustainability of agro-ecosystems. The dynamics of SOC are highly sensitive to nutrient management practices, cropping systems and residue management, particularly under intensive agriculture. Long-term fertilizer inputs, whether organic or inorganic, significantly modify the quantity and quality of soil organic matter, influencing carbon sequestration, aggregate stability and nutrient cycling (Lal, 2004; Bronick and Lal, 2005). Continuous reliance on chemical fertilizers without organic amendments has often been associated with a gradual decline in SOC, leading to soil degradation and reduced system resilience, especially in cereal-based cropping systems. Agricultural intensification in semi-arid and sub-humid regions, such as the sub-humid southern plain and Aravalli hills of Rajasthan, has increased pressure on soil carbon stocks due to high cropping intensity, limited residue returns and accelerated organic matter mineralization. Several studies have reported that long-term imbalanced fertilization or sole application of nitrogenous fertilizers results in depletion of SOC, deterioration of soil structure and reduced nutrient-use efficiency (Pagliai *et al.,* 2004; Kodešová *et al.,* 2008, 2011). In contrast, the incorporation of organic manures such as farmyard manure (FYM), either alone or in combination with balanced mineral fertilizers, has been shown to enhance SOC by supplying external carbon inputs, stimulating microbial activity and promoting physical protection of organic matter within soil aggregates (Regelink *et al.,* 2015; Basche and DeLonge, 2019). Integrated nutrient management practices are particularly effective in sustaining SOC under long-term cropping systems because they synchronize nutrient supply with crop demand while simultaneously replenishing soil carbon pools. Organic amendments improve soil aggregation and reduce carbon losses by decreasing erosion and mineralization rates, while balanced inorganic fertilization enhances biomass production and root turnover, indirectly contributing to SOC build-up. Long-term experiments have demonstrated that FYM-based and integrated fertilization systems consistently maintain higher SOC levels compared to sole chemical fertilizer treatments or unfertilized control (Singh *et al.,* 2018; Panagos *et al.,* 2014). In wheat-based cropping systems, SOC status after harvest is especially critical, as soils are exposed to erosion and rapid organic matter oxidation. Variations in fertilization practices create distinct differences in residue input, root biomass and microbial activity, which ultimately govern SOC accumulation or depletion. Understanding the comparative effects of organic and inorganic fertilizers on SOC under long-term maize–wheat rotations is therefore essential for designing sustainable nutrient management strategies. In this context, the present study was undertaken to evaluate the comparative effects of long-term application of organic and inorganic fertilizers on soil organic carbon under the maize–wheat cropping sequence in the sub-humid southern plain and Aravalli hills of Rajasthan. The study aims to identify nutrient management practices that enhance SOC sequestration and improve soil health for sustainable agricultural production in the region.

II. MATERIAL AND METHODS

Field Location and Experimental Site

The experiment was conducted under the aegis of the All India Coordinated Research Project (AICRP) on Long-Term Fertilizer Experiment at a fixed site (B_2 block) of the Instructional Farm, Rajasthan College of Agriculture, Udaipur. The present investigation represents the 26th and 27th maize–wheat cropping sequence of the long-term fertilizer experiment, which was initiated during kharif 1997. The experimental site is located in the south-eastern part of Rajasthan at an altitude of 582.2 m above mean sea level, with geographical coordinates of 24°35′ N latitude and 73°42′ E longitude. The region falls under Agro-climatic Zone IVa (Sub-humid Southern Plain and Aravalli Hills) of Rajasthan.

Experimental Details

The field experiment was conducted during the rabi seasons of 2023–24 and 2024–25 using wheat (*Triticum aestivum* L.) variety Raj 4037 as the test crop under a maize–wheat cropping system. A uniform seed rate of 100 kg ha^{-1} was maintained across all treatments. The experiment was laid out in a Randomized Block Design (RBD) comprising 12 treatments with four replications, resulting in a total of 48 experimental plots. Each gross plot measured 20.0 m × 9.0 m (180 m^2), while the net plot size was 19.0 m × 8.0 m (152 m^2). Sowing was carried out with a row-to-row spacing of 22.5 cm. All agronomic practices, including irrigation, weed control and plant protection measures, were carried out uniformly for all treatments following the recommended package of practices for wheat cultivation in the region.

Treatment Details

The experiment consisted of twelve long-term nutrient management treatments, involving combinations of organic and inorganic fertilizers, applied continuously on the same plots since 1997. The treatments were as follows:

T_1: NPK,
T_2: NPK + Zn,
T_3: NPK + Zn + S,
T_4: NPK + S,
T_5: NPK + Bio,
T_6: FYM 10 t ha^{-1} + 100% NPK (– NPK supplied through FYM),
T_7: NPK + FYM 10 t ha^{-1},
T_8: FYM 20 t ha^{-1},
T_9: 150% NPK,
T_{10}: 100% NP,
T_{11}: 100% N,
T_{12}: Control (no fertilizer).

III. ANALYSIS OF SOIL PARAMETERS

Soil Organic Carbon (SOC)

Soil samples were collected from the surface soil layer (0–15 cm depth) after the harvest of wheat during both years of investigation. The collected soil samples were air-dried, gently crushed and passed through a 2-mm sieve for laboratory analysis. Soil organic carbon content was determined using the Walkley and Black (1934) wet oxidation method, which involves oxidation of organic matter by potassium dichromate in the presence of concentrated sulfuric acid, followed by titration with ferrous ammonium sulfate. SOC content was expressed as percentage (%) of soil organic carbon, and pooled analysis was carried out by averaging the values of both years to assess the long-term influence of organic, inorganic and integrated nutrient management practices on soil carbon dynamics.

IV. Result and Discussion

It was explicit from the data (Table 1 and Figure 1) that soil organic carbon (SOC) was significantly influenced by long-term application of organic and inorganic fertilizers under the maize–wheat cropping sequence. During 2023–24, the lowest SOC content was recorded in the control (0.529%), whereas the highest SOC content was observed under FYM @ 20 t ha^{-1} (T_8: 0.985%), indicating an increase of about 86% over control. Integrated nutrient management treatments also resulted in substantial SOC build-up, with NPK + FYM 10 t ha^{-1} (T_7: 0.941%) and FYM 10 t ha^{-1} + 100% NPK (T_6: 0.920%) recording significantly higher SOC and remaining statistically at par with T_8. Sole application of chemical fertilizers showed comparatively lower SOC accumulation; recommended NPK (0.760%) and balanced fertilization with micronutrients or biofertilizers resulted in only moderate improvements, while imbalanced fertilization treatments such as 100% NP (0.693%) and 100% N (0.658%) were least effective. A similar trend was maintained during 2024–25, with SOC ranging from 0.531% in control to 0.987% in FYM 20 t ha^{-1}, and integrated treatments again performing superior to sole chemical fertilization. The pooled mean confirmed that continuous application of FYM, either alone or in combination with balanced NPK fertilization, consistently enhanced SOC by 73–86% over control, emphasizing the cumulative benefits of long-term organic inputs. The pronounced increase in SOC under FYM and integrated treatments can be attributed to direct addition of organic carbon through manure, greater crop biomass and root residue return, enhanced microbial activity and improved aggregate stability, which collectively reduce organic matter mineralization and promote carbon stabilization within soil aggregates. In contrast, sole and imbalanced chemical fertilization supply nutrients without sufficient carbon inputs, leading to limited SOC build-up under intensive cropping. These findings are in close agreement with earlier studies, which reported that long-term organic and integrated nutrient management practices are more effective than sole chemical fertilization in sustaining and enhancing SOC and overall soil health (Lal, 2004; Bronick and Lal, 2005; Regelink *et al.,* 2015; Singh *et al.,* 2018).

V. CONCLUSION

The present study clearly demonstrated that long-term application of organic and integrated nutrient management practices significantly enhanced soil organic carbon (SOC) compared to sole chemical fertilization and unfertilized control under the maize–wheat cropping system. Continuous application of FYM @ 20 t ha^{-1} (T_8) resulted in the highest SOC content, followed closely by its integration with balanced inorganic fertilization **(**T_6 and T_7**)**, indicating the strong potential of organic inputs in building and sustaining soil carbon stocks. Organic and integrated treatments increased SOC by 73–86% over control, highlighting the critical role of farmyard manure in replenishing soil carbon through direct organic matter addition and improved biomass recycling. Integrated nutrient management involving FYM and balanced NPK fertilization proved superior to sole chemical fertilization in maintaining higher SOC levels, reflecting improved carbon stabilization and reduced organic matter losses. In contrast, imbalanced fertilization treatments and sole application of nitrogen or NP were less effective in sustaining SOC, underscoring the limitations of chemical fertilizers when applied without organic amendments. The enhancement of SOC under FYM-based treatments can be attributed to improved soil aggregation, increased microbial activity and greater retention of crop residues, which collectively promote long-term carbon sequestration.

Table 1: Effect of organic and inorganic fertilization on organic carbon of soil after harvest of wheat under wheat maize cropping sequence

Treatment	**OC (%)**		
	2023-24	**2024-25**	**Pooled**
T_1: NPK	0.760	0.762	0.761
T_2: NPK + Zn	0.769	0.770	0.770
T_3: NPK + Zn + S	0.772	0.774	0.773

T_4: NPK + S	0.763	0.765	0.764
T_5: NPK + Bio	0.782	0.783	0.783
T_6: FYM 10 t + 100% NPK (- NPK of FYM)	0.920	0.921	0.921
T_7: NPK + FYM 10 t ha^{-1}	0.941	0.943	0.942
T_8: FYM 20 t ha^{-1}	0.985	0.987	0.986
T_9: 150% NPK	0.814	0.816	0.815
T_{10}: 100% NP	0.693	0.695	0.694
T_{11}: 100% N	0.658	0.659	0.658
T_{12}: Control	0.529	0.531	0.530
S.Em. ±	0.069	0.071	0.046
C.D. (P= 0.05)	0.199	0.206	0.131

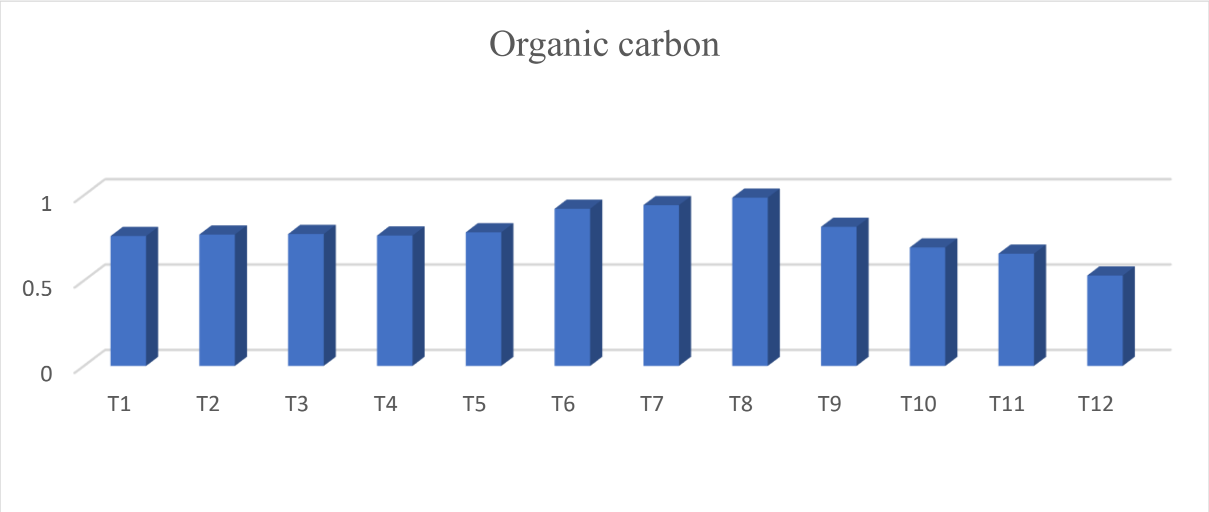

Fig.1: Effect of organic and inorganic fertilization on organic carbon of soil after harvest of wheat under wheat maize cropping sequence

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Influence of long-term application of organic and inorganic fertilizers on soil microbial properties

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***Abstract*— *A long-term field experiment was coducted during 2023–24 and 2024–25 at the Instructional Farm, Rajasthan College of Agriculture, Udaipur, to evaluate the effect of organic and inorganic nutrient management practices on soil microbial populations. The experiment was laid out in a randomized block design with twelve treatments comprising sole chemical fertilizers, organic manure, biofertilizers, and their integrated combinations. Soil microbial populations, including bacteria (cfu × 10^6), fungi (cfu × 10^4), and actinomycetes (cfu × 10^5), were analyzed and pooled data were used for interpretation. The results indicated that microbial populations were significantly influenced by different nutrient management treatments. Among all treatments, application of FYM @ 20 t ha^{-1} (T_8) recorded the highest pooled bacterial population (34.30 cfu × 10^6), fungal population (18.57 cfu × 10^4), and actinomycetes population (19.91 cfu × 10^5), followed by NPK + FYM @ 10 t ha^{-1} (T_7), which recorded pooled values of 31.71, 16.82, and 17.70, respectively. Integrated application of FYM 10 t ha^{-1} + 100% NPK (T_6) also resulted in higher microbial populations with pooled bacterial, fungal, and actinomycetes counts of 28.96, 16.35, and 17.38, respectively. In contrast, imbalanced fertilizer treatments such as 100% N (T_{11}) and control (T_{12}) recorded the lowest microbial populations, with pooled bacterial counts of 7.88 and 7.24, fungal counts of 7.43 and 5.52, and actinomycetes counts of 6.91 and 6.16, respectively. Pooled analysis confirmed that continuous application of FYM, either alone or in combination with chemical fertilizers, was most effective in enhancing soil microbial populations. The study highlights the importance of organic and integrated nutrient management practices in improving soil biological health and sustaining soil fertility.*

Keywords*— *Soil microorganisms, bacteria, fungi, actinomycetes, integrated nutrient management, farmyard manure

I. INTRODUCTION

Soil microorganisms are integral components of the soil ecosystem and play a crucial role in nutrient cycling, organic matter decomposition, and maintenance of soil fertility. Microbial populations such as bacteria, fungi, and actinomycetes regulate biochemical transformations of carbon, nitrogen, phosphorus, and other essential nutrients, thereby influencing plant growth and soil productivity (Brady and Weil, 2017; Subbarao, 1999). Due to their rapid response to changes in soil management practices, soil microbial properties are widely used as sensitive indicators of soil health and sustainability. The long-term application of inorganic fertilizers has significantly contributed to increased agricultural production; however, continuous and imbalanced use of chemical fertilizers has been reported to adversely affect soil biological properties. Prolonged application of mineral fertilizers without organic inputs often leads to depletion of soil organic matter and reduction in microbial diversity and activity (Goyal et al., 1999). Such practices may suppress beneficial microbial populations and negatively impact soil biological functioning over time.

In contrast, organic amendments such as farmyard manure (FYM) supply organic carbon and essential nutrients that serve as energy sources for soil microorganisms, thereby enhancing microbial biomass and activity. Several studies have demonstrated that organic nutrient sources improve soil structure, moisture retention, and aeration, creating a favorable environment for microbial proliferation (Mäder et al., 2002). The addition of organic manures has also been shown to stimulate populations of bacteria, fungi, and actinomycetes, leading to improved nutrient availability and soil health. Long-term fertilizer experiments provide valuable information on the cumulative effects of nutrient management practices on soil biological properties. Integrated nutrient management, involving the combined use of organic manures and inorganic fertilizers, has been recognized as a sustainable approach for maintaining soil fertility and enhancing microbial activity (Yadav et al., 2017). Balanced fertilization ensures adequate nutrient supply to crops while minimizing the adverse impacts of sole chemical fertilizer application on soil biological processes. Different microbial groups respond differently to fertilization practices. Bacteria dominate in nutrient-rich environments and are primarily responsible for rapid nutrient mineralization, whereas fungi play an important role in decomposition of complex organic residues and soil aggregation. Actinomycetes contribute to the breakdown of resistant organic compounds and are particularly important in maintaining soil biological stability under long-term management practices (Subbarao, 1999; Brady and Weil, 2017). Therefore, understanding the influence of long-term application of organic and inorganic fertilizers on soil microbial properties is essential for developing sustainable nutrient management strategies. Such knowledge is critical for improving soil biological health, sustaining crop productivity, and ensuring long-term sustainability of intensive agricultural systems.

II. MATERIALS AND METHODS

Field Location and Experimental Site

The study was carried out under the All India Coordinated Research Project (AICRP) on Long-Term Fertilizer Experiment at a permanent experimental site (B2 block) located at the Instructional Farm of the Rajasthan College of Agriculture, Udaipur. The present investigation corresponds to the 26th and 27th maize–wheat cropping cycles of the long-term fertilizer experiment, which has been in continuous operation since *kharif* 1997. The experimental site is situated in the south-eastern region of Rajasthan at an elevation of 582.2 m above mean sea level and lies between 24°35′ N latitude and 73°42′ E longitude. The area falls within Agro-climatic Zone IVa, designated as the Sub-humid Southern Plain and Aravalli Hills region of Rajasthan.

Experimental Details

The field experiment was conducted during the *rabi* seasons of 2023–24 and 2024–25 using wheat (*Triticum aestivum* L.) variety Raj 4037 under a maize–wheat cropping system. A uniform seed rate of 100 kg ha^{-1} was used for all treatments. The experiment was laid out in a Randomized Block Design (RBD) with twelve treatments and four replications, comprising a total of 48 experimental plots. Each plot had a gross size of 20.0 m × 9.0 m (180 m²) and a net plot size of 19.0 m × 8.0 m (152 m²). Sowing was performed with a row spacing of 22.5 cm. All recommended agronomic practices, including irrigation scheduling, weed management, and plant protection measures, were uniformly adopted across all treatments in accordance with the regional package of practices for wheat cultivation.

Treatment Details

The experiment included twelve long-term nutrient management treatments consisting of organic manures, inorganic fertilizers, and their combinations, which have been applied continuously on the same experimental plots since 1997. The treatment details were as follows:

T_1: NPK
T_2: NPK + Zn
T_3: NPK + Zn + S
T_4: NPK + S
T_5: NPK + Bio
T_6: FYM 10 t ha^{-1} + 100% NPK (NPK adjusted for nutrients supplied through FYM)
T_7: NPK + FYM 10 t ha^{-1}
T_8: FYM 20 t ha^{-1}
T_9: 150% NPK
T_{10}: 100% NP
T_{11}: 100% N
T_{12}: Control (no fertilizer application)

III. ANALYSIS OF SOIL PARAMETERS

Soil Microbial Properties

Soil samples were collected from the surface soil layer (0–15 cm depth) after the harvest of wheat during both years of investigation. The collected samples were immediately brought to the laboratory and gently crushed by hand to break large clods, followed by removal of visible plant residues and stones. The soil samples were then passed through a 2-mm sieve and stored under refrigerated conditions until further analysis to preserve microbial activity.

The soil microbial populations were estimated using the serial dilution and plate count technique. Bacterial populations were enumerated using nutrient agar medium, fungi were estimated on potato dextrose agar medium, and actinomycetes were determined using actinomycetes isolation agar. Appropriate serial dilutions were prepared from each soil sample using sterile distilled water, and aliquots were plated on respective culture media under aseptic conditions. The inoculated plates were incubated at suitable temperatures for specific durations, after which the colonies were counted. Microbial populations were expressed as colony-forming units (cfu) per gram of soil, with bacterial counts expressed as cfu × 10^6 g^{-1} soil, fungal counts as cfu × 10^4 g^{-1} soil, and actinomycetes counts as cfu × 10^5 g^{-1} soil. Observations recorded for individual years were subjected to pooled analysis by averaging the data of both years to evaluate the long-term effects of organic, inorganic, and integrated nutrient management practices on soil microbial properties.

IV. RESULT AND DISCUSSION

It was evident from the data (Table 1 and Figure 1) that soil microbial populations were significantly influenced by the long-term application of organic and inorganic fertilizers under the maize–wheat cropping system. The pooled data revealed wide variation in bacterial, fungal, and actinomycetes populations across different nutrient management treatments, indicating differential responses of soil microorganisms to long-term fertilization practices. Among the treatments, application of FYM @ 20 t ha^{-1} (T_8) recorded the highest pooled microbial populations, with bacterial count of 34.30 cfu × 10^6 g^{-1} soil, fungal population of 18.57 cfu × 10^4 g^{-1} soil, and actinomycetes population of 19.91 cfu × 10^5 g^{-1} soil. This represented a substantial increase over the control treatment (T_{12}), which recorded the lowest microbial populations, with pooled bacterial, fungal, and actinomycetes counts of 7.24, 5.52, and 6.16 cfu × 10^5 g^{-1} soil, respectively. The pronounced improvement in microbial populations under T_8 clearly indicates the beneficial effect of continuous organic manure application on soil biological health. Integrated nutrient management treatments also resulted in significantly higher microbial populations compared to sole chemical fertilizer application. The treatment NPK + FYM @ 10 t ha^{-1} (T_7) recorded pooled bacterial, fungal, and actinomycetes populations of 31.71, 16.82, and 17.70 cfu × respective units, while FYM 10 t ha^{-1} + 100% NPK (T_6) registered corresponding values of 28.96, 16.35, and 17.38. These treatments remained statistically at par with FYM @ 20 t ha^{-1} and were markedly superior to treatments receiving only inorganic fertilizers. Balanced fertilization treatments involving micronutrients, sulphur, and biofertilizers showed moderate improvement in microbial populations, whereas imbalanced fertilization treatments such as 100% NP (T_{10}) and 100% N (T_{11}) recorded relatively lower microbial counts. The enhanced microbial populations under FYM and integrated treatments may be attributed to continuous supply of organic carbon and nutrients, which serve as energy sources for soil microorganisms and improve soil physical conditions such as aggregation, aeration, and moisture retention. The addition of organic matter also stimulates microbial proliferation by increasing substrate availability and promoting favorable microhabitats. In contrast, sole application of chemical fertilizers supplies nutrients without adding organic carbon, thereby limiting microbial growth under long-term intensive cropping. The observed findings are in close conformity with earlier studies, which reported that long-term application of organic manures, either alone or in combination with inorganic fertilizers, significantly enhances soil microbial populations and biological activity compared to exclusive use of chemical fertilizers (Goyal et al., 1999; Mäder et al., 2002; Yadav et al., 2017). Thus, the results clearly demonstrate that organic and integrated nutrient management practices are more effective in sustaining soil microbial properties and improving long-term soil health.

Table 1: Effect of organic and inorganic fertilization on bacterial, fungal and actinomycetes population of soil after harvest of wheat under wheat maize cropping sequence

Treatment	Bacteria (cfu x 10^6)			Fungi (cfu x 10^4)			Actinomycetes (cfu x 10^5)		
	2023-24	2024-25	Pooled	2023-24	2024-25	Pooled	2023-24	2024-25	Pooled
T_1: NPK	16.45	17.00	16.73	12.36	14.00	13.18	12.84	12.87	12.86
T_2: NPK + Zn	18.74	19.06	18.90	12.61	12.65	12.63	13.00	13.04	13.02
T_3: NPK + Zn + S	20.61	20.99	20.80	13.82	13.87	13.85	13.68	13.70	13.69
T_4: NPK + S	18.90	19.15	19.03	13.16	13.19	13.18	13.37	13.41	13.39

T_5: NPK + Bio	23.72	30.00	26.86	12.29	12.31	12.30	12.91	12.95	12.93
T_6: FYM 10 t + 100% NPK (- NPK of FYM)	28.79	29.13	28.96	16.33	16.36	16.35	17.35	17.40	17.38
T_7: NPK + FYM 10 t ha^{-1}	31.44	31.98	31.71	16.80	16.84	16.82	17.68	17.71	17.70
T_8: FYM 20 t ha^{-1}	33.96	34.64	34.30	18.55	18.59	18.57	19.85	19.97	19.91
T_9: 150% NPK	19.08	19.72	19.40	14.49	14.51	14.50	14.80	14.83	14.82
T_{10}: 100% NP	14.92	15.63	15.28	9.94	9.96	9.95	9.88	9.91	9.89
T_{11}: 100% N	7.86	7.90	7.88	7.42	7.45	7.43	6.89	6.92	6.91
T_{12}: Control	7.22	7.25	7.24	5.51	5.53	5.52	6.15	6.17	6.16
S.Em. $\pm$	0.167	0.198	0.120	0.195	0.202	0.131	0.145	0.236	0.125
C.D. (P= 0.05)	0.481	0.571	0.338	0.562	0.580	0.370	0.418	0.679	0.354

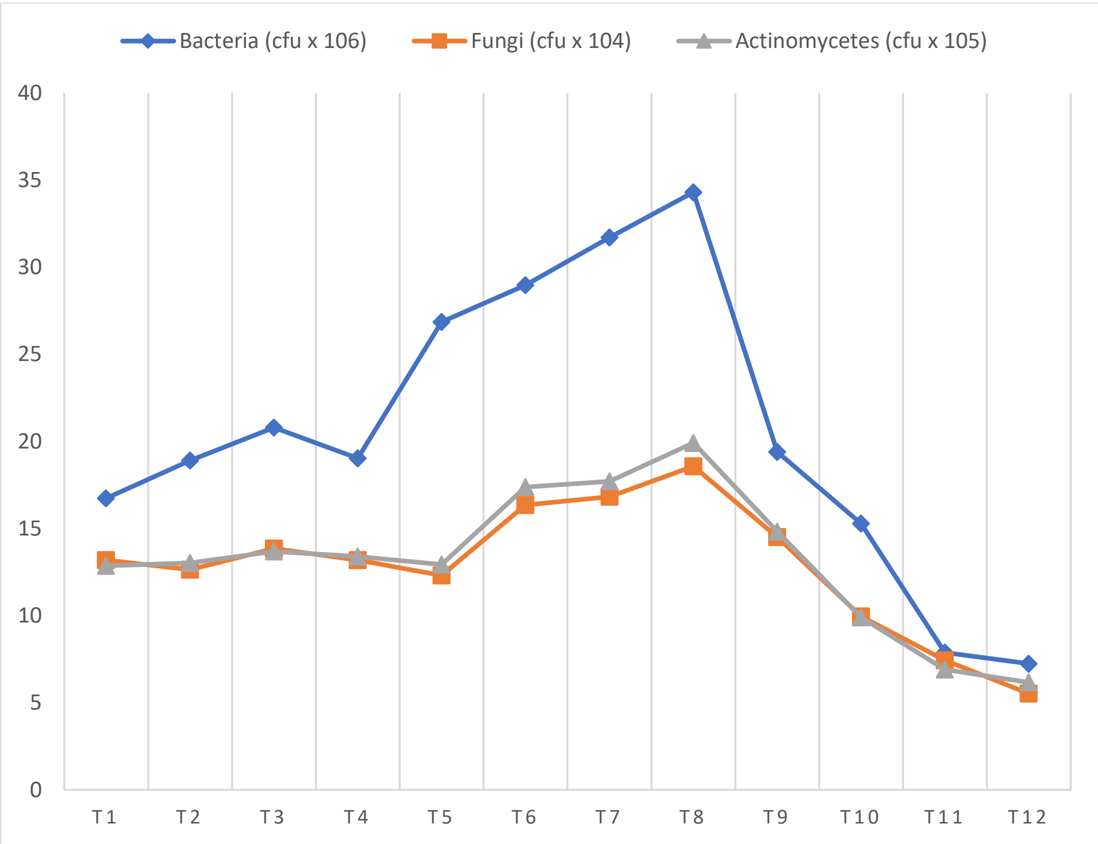

Fig.1: Effect of organic and inorganic fertilization on bacterial, fungal and actinomycetes population of soil after harvest of wheat under wheat maize cropping sequence

V. CONCLUSION

The results of the long-term fertilizer experiment clearly demonstrate that soil microbial properties were significantly influenced by different organic and inorganic nutrient management practices under the maize–wheat cropping system. Continuous application of farmyard manure (FYM), either alone or in combination with chemical fertilizers, proved to be most effective in enhancing soil microbial populations, including bacteria, fungi, and actinomycetes. The highest microbial counts were consistently recorded under FYM @ 20 t ha^{-1}, followed by integrated nutrient management treatments involving FYM and recommended NPK fertilizers, indicating the cumulative and beneficial effects of organic carbon inputs on soil biological health. In contrast, sole application of chemical fertilizers, particularly imbalanced treatments such as 100% N and 100% NP, resulted in comparatively lower microbial populations, reflecting their limited role in sustaining soil biological activity under long-term intensive cultivation. Balanced fertilization practices supplemented with micronutrients and biofertilizers showed moderate improvements but were inferior to organic and integrated approaches.

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Flood Disaster Management in India: Lessons from Uttarakashi and Punjab

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***Abstract*— *India, one of the fastest-growing economies, remains highly dependent on agriculture for livelihood and food security. However, extreme weather events in 2025 severely disrupted this sector, particularly due to floods in Uttarakashi and Punjab. In Uttarakashi, intense cloudbursts triggered flash floods and landslides, causing significant loss of life, damage to infrastructure, and destruction of agricultural land in the fragile Himalayan region. Rescue operations indicated large-scale displacement and severe geomorphological changes in affected valleys. In contrast, Punjab experienced widespread riverine flooding due to prolonged monsoon rainfall, submerging nearly 2 lakh hectares of cropland and affecting thousands of farming households. Major crops such as paddy, maize, and sugarcane suffered heavy losses, resulting in an estimated decline of nearly 15% in agricultural output and substantial economic damage. The contrasting flood characteristics highlight the differing vulnerabilities of mountainous and plain regions where flash floods in Uttarakhand caused localized but intense destruction, while prolonged inundation in Punjab led to large-scale agricultural and economic losses. The study underscores the urgent need for region-specific flood mitigation strategies, climate-resilient agricultural planning, and improved early warning systems to reduce future risks and enhance sustainability in India's agrarian economy.*

***Keywords*— Disaster, Flood, Risk, Management**

I. STUDY AREA

Uttarkashi, in the northern Himalayas of India, is situated between the coordinates of 30.73° North latitude and 78.45° East longitude. It is located in the upper valley of the river Bhagirathi, which is one of the largest Ganga tributaries feeding into Haridwar and a part of the Garhwal Himalayas in Uttarakhand, India. The geographical features of the district include mountainous, valleyous, glaciated, and high-altitude river valley areas. Uttarkashi is internationally recognized as the "doorway to the holy Hindu shrines of Gangotri, the Birthplace of the Ganga, and YAMUNOTRI." Apart from its religious significance, the region is also fragile from an ecological and geographical perspective, and is prone to landslides, cloudbursts, earthquakes, and floods, in line with the young Himalayas in the region. Some researchers i.e. Chauhan et al. (2023), Ishaq (2023), Malik et. al. (2025), Panwar et. al. (2024), Parveen et. al. (2013), Shukla et. al (2013 and Theophilus (2013) also worked in the particular field.

Punjab, situated in the northwestern part of India, extends between 29.5° N to 32.5° N latitudes and 73.8° E and 76.9° E longitudes. The province is located in the Indo-Gangetic Plain, bordered by Pakistan to the west and several other Indian provinces to the east and south. The province acquired the name "land of five rivers," which are the Sutlej, Beas, Ravi, Chenab, and Jhelum rivers, making it the most fertile region in terms of agriculture. Punjab has earned the name Granary of India as it plays an important part in the food security of the nation, especially with respect to the generation of food products like wheat and rice. The flat terrain with a vast water supply network and rich alluvial soil does not allow it to be as productive as before due to the flood occurrence, which takes place due to the high rainfall of the monsoon season. Figure 1 shows the graphical location of two locations.

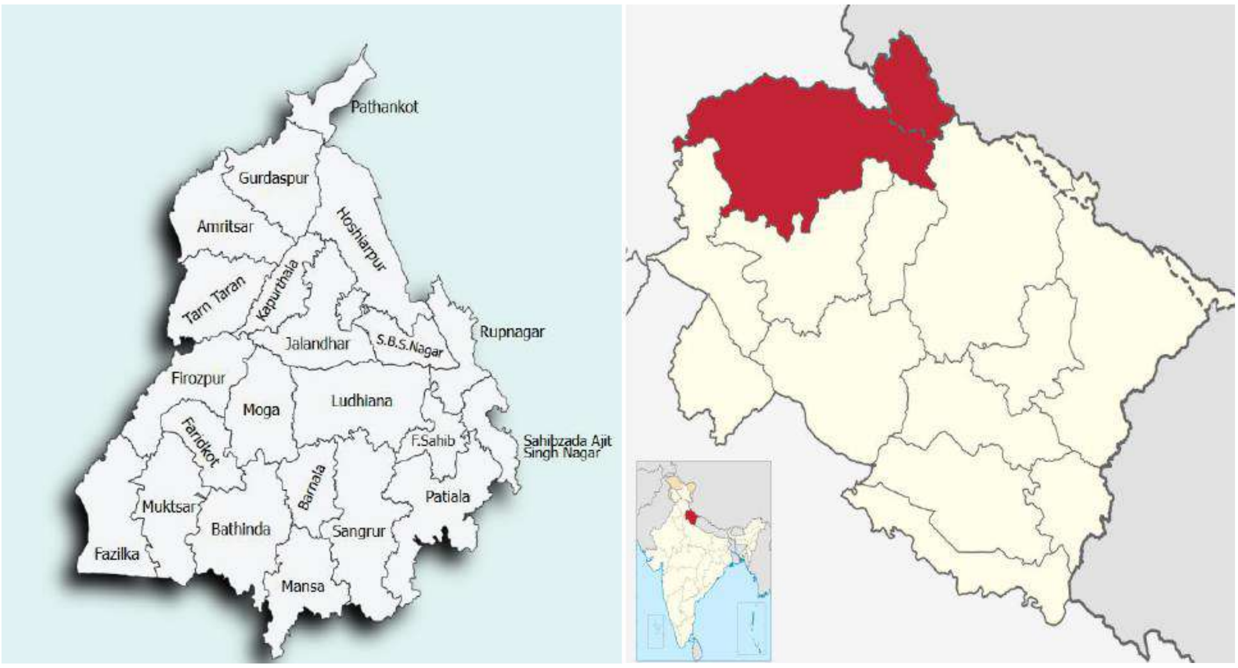


Fig.1: Geographical Map of Punjab and Uttarkashi

II. RAINFALL ANALYSIS DURING MANSON SEASON FOR PUNJAB

The rainfall data indicate that August and September received significantly higher precipitation than normal, contributing to an above-average monsoon season in 2025. In contrast, June and July rainfall remained close to the long-term average, indicating an uneven temporal distribution of rainfall. Table 1 and Figure 2 shows the rainfall distribution in 2025.

Flood Impact Assessment in Punjab (2025)

Owing to exceptionally heavy rainfall and a significant rise in the water levels of the Ravi and Beas rivers, coupled with the regulated discharge from the Ranjit Sagar Dam, the state of Punjab experienced severe flood conditions beginning on 27 August 2025. The situation rapidly escalated into a large-scale hydro-meteorological disaster, affecting all 23 districts of the state.

According to consolidated data received from the State Emergency Operations Centre, Punjab, a total of 2,287 villages were impacted by flooding. The cumulative assessment of damages and losses recorded from 01 June 2025 onwards indicates substantial human, infrastructural, and agricultural losses. A total of 52 human fatalities were reported, while 4 individuals remained missing and 25 persons sustained injuries. The floods affected approximately 3,87,907 people, necessitating large-scale evacuation and rescue operations. In total, 23,049 individuals were safely rescued or evacuated to safer locations. Residential infrastructure suffered extensive damage, with 7,406 houses affected, including 5,379 pucca houses and 2,027 kutcha houses. The agricultural sector experienced significant losses, with approximately 1,80,412.229 hectares of cultivated land inundated, adversely impacting crop productivity and rural livelihoods. Relief and rehabilitation measures included the establishment of 219 relief camps, sheltering 7,604 displaced persons. Additionally, the flooding caused severe damage to border infrastructure, particularly along the Indo-Pak border. Approximately 80 km of Border Security Fence was damaged, 3 Border Outposts (BOPs) were completely washed away, 67 BOPs were partially damaged, and 15 BOPs were fully vacated, while 118 BOPs were partially vacated as a precautionary measure. Table 2 shows the impact of the flood in Punjab during 2025.

Table 1: Monthly Rainfall Distribution in 2025 in the Manson Season (IMD-2025)

Months	***Actual (mm)***	***Normal (mm)***
June	69.7	54.5
July	146.9	161.4
August	253.7	146.2
September	150.6	77.7
June-July (1st Half)	216.6	215.9
August-September (2nd Half)	404.3	223.9

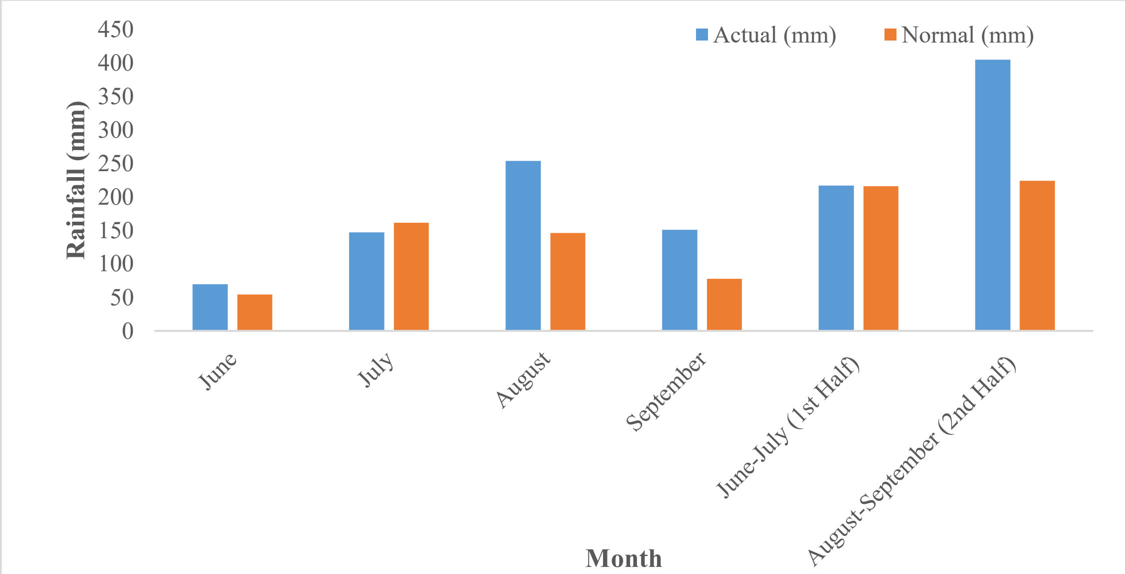


Fig.2: Rainfall analysis for the Manson season for July-September 2025

Table 2: Summary of Flood Impact in Punjab (2025) (IMD-2025)

Category	**Details**
Period of Impact	From 01 June 2025 onwards
Cause of Flooding	Heavy rainfall, rise in water level of Ravi & Beas rivers, discharge from Ranjit Sagar Dam
Total Districts Affected	23
Total Villages Affected	2,287
Population Affected	3,87,907
Deaths	52
Missing Persons	4
Injured Persons	25
People Rescued / Evacuated	23,049
Total Houses Damaged	7,406
Pucca Houses Damaged	5,379
Kutcha Houses Damaged	2,027
Agricultural Loss	1,80,412.229 hectares of cropped area affected
Number of Relief Camps	219
Inmates in Relief Camps	7,604

Border Security Fence Damaged	80 km
BSF Border Outposts (BOPs) Washed Away	3
BSF BOPs Partially Damaged	67
BSF BOPs Fully Vacated	15
BSF BOPs Partially Vacated	118

(a)

(b)

(c)

Fig.3 (a, b, and c): Flood incident in Punjab in 2025

III. RAINFALL ANALYSIS DURING MANSON SEASON FOR UTTARAKHAND

The rainfall data reveal that August recorded the highest precipitation, significantly exceeding the normal average, indicating intense monsoonal activity. Although July received slightly lower rainfall than normal, overall monsoon rainfall remained above average due to substantial rainfall in June and September. Table 3 and Figure 4 show the rainfall distribution in 2025.

Table 3: Monthly Rainfall Distribution in 2025 in the Manson Season

Months	***Actual (mm)***	***Normal (mm)***
June	240.7	176.8
July	350.7	417.8
August	574.4	385.7
September	255.2	182.4

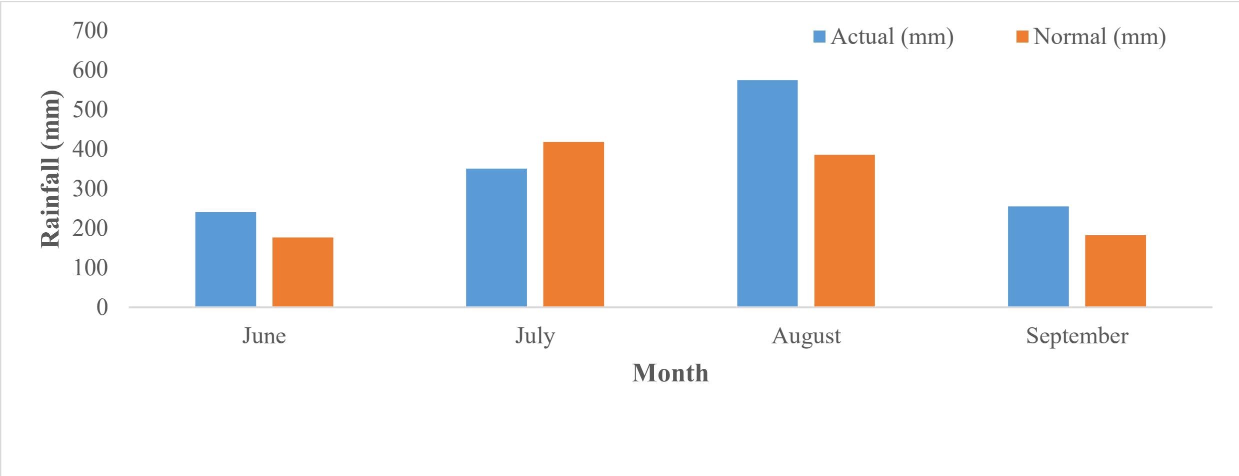


Fig.4: Rainfall analysis for the Manson season for July-September 2025

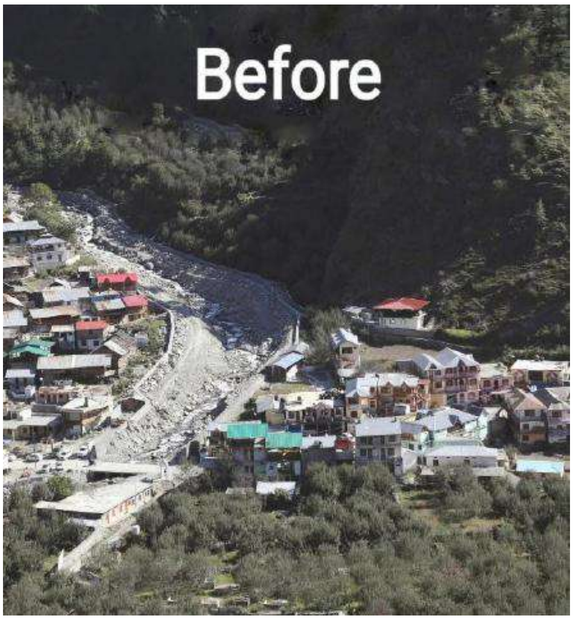
Table 4: Summary of Flood Impact in Uttarakhand (2025) (IMD-2025)

Category	***Details***
Cloudburst	Occurred in Dharali village, Uttarkashi district on 05 August 2025 at 13:50 hrs
Waterlogging	Reported at Yamunotri National Highway, Syanchatti on 21 August 2025 at 16:25 hrs
Deaths	71
Missing Persons	99
Injured Persons	69
Total Houses Affected	2,682
Fully Damaged Houses	308
Partially Damaged Houses	2,374
Cow Sheds Damaged	50
Total Livestock Lost	204
Large Animals	89
Small Animals	115

Monsoon Situation in Uttarakhand (2025)

During the ongoing southwest monsoon season of 2025, the state of Uttarakhand has experienced multiple hydro-meteorological disasters resulting in significant human, infrastructural, and livestock losses. One of the major incidents was a cloudburst event reported on 05 August 2025 at approximately 13:50 hours in Dharali village, Uttarkashi district, which triggered sudden flash flooding and extensive local damage. In addition, severe waterlogging was reported along the Yamunotri National Highway near Syanchatti on 21 August 2025 at around 16:25 hours, disrupting transportation and posing serious risks to pilgrims and residents.

According to the consolidated damage assessment reports, the cumulative impact of the ongoing monsoon has been substantial. A total of 71 human fatalities have been reported, while 99 persons remain missing and 69 individuals sustained injuries due to flood- and landslide-related incidents. Residential infrastructure suffered considerable damage, with 2,682 houses affected, of which 308 houses were fully damaged, and 2,374 houses were partially damaged. The disaster also resulted in significant losses to livestock and rural livelihoods. A total of 204 livestock deaths were recorded, comprising 89 large animals and 115 small animals, along with damage to 50 cow sheds. These losses have had a direct adverse impact on the agrarian and pastoral communities of the affected regions. Table 4 shows the impact of flood analysis in Uttarakhand 2025 and Figure 5 (a, b and c) shows the flood condition in different region of Uttarakhand.



(a)

(b)

(c)

Fig.5: (a, b, and c): Flood incident in Uttarakhand in 2025

IV. MITIGATION AND PREVENTION OF FLOOD DISASTER OCCURRENCES

The frequent occurrences of flood events in the regions of Punjab and Uttarakhand during the monsoon season in the year 2025 have established a clear necessity to develop an integrated flood risk management plan. Taking into consideration the rising trends of hydro-meteorological extreme events, a multi-dimensional plan should be formulated.

1. Enhancing Hydrological Data Gathering and Early Warning Mechanisms

Modules for advanced hydro-meteorological monitoring should also be augmented over sensitive river basins, especially the Ravi, Beas, and Himalayan river basins. Real-time monitoring systems of rainfall, river discharges, and water levels of reservoirs combined with satellite-based forecasting systems should greatly improve early warning systems. These should be followed by effective communication systems of early warnings through digital media, mobile communication systems, and administrative channels for early evacuations, thereby preventing loss of lives.

2. Scientific Reservoir Operation and Dam Management

Procedures for the coordination of reservoir operations must be formulated for large hydraulic structures like the Ranjit Sagar Dam. Real-time flow forecasting-based rule curves must be provided to control the controlled water releases to avoid flood risks. Collaboration of the agencies of the dam, the agency of disaster management, and the administrative units of the locations must be ensured.

3. Enhancing Flood Control Infrastructure

Embankment reinforcement, riverbank protection, desilting of rivers, and flood protection walls in vulnerable areas should receive high priority among structural measures. In a region like Uttarakhand, with mountains, protective measures like check dams and debris barriers will help significantly in reducing landslide and flood hazards.

4. Land-Use Planning and Zoning Regulation

The enforcement of the zoning rules of land use is vital in preventing the emergence of unplanned settlements in floodplains and high-risk areas. Flood hazard maps created using geographic information systems must be used to develop the areas in the future. The relocation of the vulnerable settlements to a safe area must be achieved through the rehabilitation of the area.

5. Strengthening Community-Based Disaster Preparedness

The community awareness initiatives concerning flood preparedness, evacuation, and first response drills need to be upgraded. Formation of community disaster response teams and conducting drills can be a great way to improve flood preparedness and quick response to the event.

6. Climate-Resilient

Climate-resilient standards must be adopted in infrastructure development projects in flood-prone areas. Elevated roads, flood-resistant housing, strengthened drainage infrastructure, and flood-protected public utilities should be used to withstand severe flooding conditions.

7. Ecosystem-Based Approaches and Environmental Conservation

Wetlands, floodplains, and drainage channels can be restored for increased retention of water and mitigation of peak runoff. Tree planting in upland catchments, especially in the Himalayan region, is critical in enhancing the management of runoff, landslide prevention, and control of soil erosion.

V. CONCLUSION

The 2025 flood events in Uttarakhand and Punjab clearly demonstrate the increasing intensity and spatial variability of hydro-meteorological disasters in India, driven by extreme rainfall, altered river regimes, and growing anthropogenic pressures. In Uttarakhand, cloudburst-induced flash floods and landslides resulted in 71 fatalities, 99 missing persons, 69 injuries, and damage to 2,682 houses, along with the loss of 204 livestock. These impacts were concentrated in fragile Himalayan terrains, where steep slopes, high relief, and unregulated development amplified disaster severity. Conversely, Punjab experienced widespread riverine flooding, affecting 2,287 villages and 3.87 lakh people, with 1.80 lakh hectares of agricultural land inundated and 7,406 houses damaged. This highlights the vulnerability of intensively cultivated floodplains to prolonged monsoonal rainfall and regulated dam releases.

The scale of damage spanning 52 human fatalities, 23,049 evacuations, and extensive agricultural and infrastructural losses in Punjab, alongside severe geomorphological and livelihood impacts in Uttarakhand, emphasizes the inadequacy of existing flood preparedness and response mechanisms. The data clearly indicate that while Uttarakhand disaster profile is dominated by short-duration, high-intensity events such as cloudbursts and landslides, Punjab faces prolonged inundation due to river overflow and backwater effects, necessitating region-specific mitigation strategies.

These findings underscore the urgent need for an integrated flood risk management framework incorporating real-time hydro-meteorological monitoring, reservoir operation optimization, and advanced early warning dissemination systems. Strengthening land-use planning, enforcing floodplain zoning, restoring natural drainage and wetlands, and adopting climate-resilient infrastructure are essential to reducing future losses. Furthermore, community-based preparedness, combined with institutional coordination among disaster management, irrigation, and meteorological agencies, is critical for enhancing adaptive capacity.

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Trends in Area, Production and Productivity of Wheat—A Time-Series Analysis

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Abstract— *An attempt has been made in this paper to examine the status in terms of area, production and productivity of wheat in India, Himachal and Kangra district by using time-series data of the recent past two decades (2001-02 to 2022-23). Over recent years, India has shown a positive trend in wheat production and productivity, largely due to high-yielding varieties and supportive government policies. In contrast, Himachal Pradesh and Kangra district exhibit more varied trends, with some areas showing a decline in cultivation area due to a shift towards commercial crops like fruits and vegetables, while productivity in certain regions has increased due to improved farming practices. The total area under wheat cultivation in India has shown an overall decreasing trend, growing from approximately 44,904 thousand hectares in2001-02 to 41,401 thousand hectares in 2022-23. Production has increased significantly, reaching a record 113,500 thousand tonnes in 2022-23 in India. The national average productivity has marginally improved, reaching approximately 2.74 MT/ha. Major wheat-growing states like Punjab and Haryana generally have higher productivity than the national average. In Himachal Pradesh, the area under wheat cultivation has experienced a fluctuating trend. While wheat remains the principal food grain crop covering a significant portion of the total cultivated area, there is a general trend of shifting cultivated land towards non-food grain or commercial crops in some areas. Production has also fluctuated in Himachal, reaching a high of 687.45 thousand tonnes in 2004-05 but decreasing in subsequent years before rising to 609.31 thousand tonnes in 2022-23. The state's average yield was reported at 1.91 MT/ha in 2023-23. Kangra has historically been a leading wheat-growing district in the state. However, similar to the broader state trend, some studies indicated a decline in the proportionate area under wheat, with farmers shifting to more remunerative options like vegetables and fruits. The district Kangra consistently ranks in the high-productivity zone within Himachal Pradesh, benefiting from favorable climatic conditions and effective water management. Declining farm sizes due to fragmentation, urbanization, and a shift in some areas to high-value commercial crops pose a challenge to sustained wheat area and production.*

Keywords— *Area, Production, Productivity, wheat, India, Himachal, Kangra distrct.*

I. INTRODUCTION

Wheat is one of the most widely cultivated and consumed cereal in the world, serving as a staple food for a large part of the global population. In 2023, it was grown on 224 million hectares worldwide, with a total production of around 799 million tonnes (FAO, 2024). In India, wheat is the second-most important food grain after rice in terms of area, production and consumption. During 2024–25, wheat was cultivation on 32.8 million hectares, with a total production of 113.3 million tonnes and an average yield of 3.56 tonnes per hectare (USDA, 2024). India is the second-largest wheat producer globally, following China.

India has an extensive agriculture landscape, with wheat considered as a major Rabi crop. It forms a key component of the country's food grain basket and is extensively grown across the Indo-Gangetic plains, which include major states like Uttar Pradesh, Punjab, Haryana, Madhya Pradesh, Rajasthan, and Bihar. Area under wheat cultivation in India is 32.8 million hectares, yielding a total production of 113.3 million tonnes (USDA, 2024). The average yield has been reported 3.56 tonnes per hectare, with variations across states depending on soil quality, irrigation access, input use and climate conditions (DAC&FW, 2024).

The production trends in recent years show a steady increase due to improved varieties, timely sowing, and better technology and management practices. However, there are significant regional disparities in productivity. Punjab and Haryana report yields above 4.5 tonnes per hectare, while states like Madhya Pradesh and Rajasthan report yields vary between 2.8 to 3.5 tonnes (ICAR, 2023). These differences draw attention to the need for targeted interventions in input distribution, technology adoption, and extension services. Moreover, the wheat sector in India is influenced by factors such as the Minimum Support Price (MSP), procurement policies, which play a key role in production decisions and market flows (CACP, 2024).

Although wheat production in India has shown steady growth, there is still a massive disparity between per capita demand and supply due to massive waste, which largely results from poor storage facilities, insufficient transport infrastructure, and poor post-harvest practices. It is estimated that post-harvest losses in wheat was found 4 to 6 per cent of total production (NABARD, 2023). Damage caused by rodents, insects, moisture, and rough handlings are commonly reported, especially due to lack of modern storage facilities (Singh et al., 2023).

Despite being a net exporter in certain years, India has had to occasionally reduce wheat exports to manage domestic availability and control inflation. This highlights the delicate balance between surplus production and internal demand. In this context, ensuring efficient production, processing, and marketing systems, along with value addition, is essential not only for food security and farmer welfare but also for stabilizing domestic supply and enhancing export potential.

In Himachal Pradesh, wheat is grown predominantly during the Rabi season (October to April). Due to the state's diverse agro-climatic zones, wheat is cultivated across mid-hills, low-hill sub-tropical, and high-hill temperate regions. The major wheat-producing districts of Himachal Pradesh include Kangra, Mandi, Hamirpur, Una, and Bilaspur. Among these regions, Kangra has consistently ranked first in both area and production of wheat. Wheat was cultivated over 319.47 thousand hectares in the state during 2022–23, producing 609.31 thousand metric tonnes (Department of Economics and Statistics Himachal Pradesh, 2023). The average yield of wheat across the state was 1.91 MT per hectare, lower than the national average due to terrain-related constraints and limited mechanization (Agricultural Statistics at a Glance, 2023).). In Kangra district, wheat production reached 137.4 thousand tonnes over 66.80 thousand hectares in 2022–23, accounting for nearly one-fifth of the state's total output (Department of Economics and Statistics Himachal Pradesh, 2023). The dominance of wheat in the cropping pattern is largely due to its compatibility with the local climate, soil fertility, and availability of assured irrigation from canal and groundwater sources. With this background in view an attempt has been made in this paper to examine the trends in terms of area, production and productivity of wheat in India, Himachal and Kangra district. Such an analysis would have direct implication on entire agriculture.

II. SOURCES OF DATA AND ANALYSIS

For the analysis of data over the year on area, production and productivity of wheat in India, Himachal and Kangra district, relevant data were collected from the various government offices of the state and the various international sites such as FAO, USDA. While the data for the leading producers of the world were taken from the FAO STAT, 2022; the time-series data required for conducting this study over a span of recent past two decades were collected and taken from the Directorate of Economics and Statistics, Government of Himachal Pradesh (2022-23); Statistical Abstract of Himachal Pradesh; and Ministry of Agriculture & Farmers Welfare, Government of India (2022).

III. RESULTS AND DISCUSSION

3.1 Status of wheat production at global level:

The global wheat production scenario of 2022–23 highlights China as the world's largest producer, accounting for 136.6 million tonnes, followed closely by India with 134.3 million tonnes as presented in Table 3.1 Together, these two countries dominate the global wheat market, contributing more than one-third of total production. Russia at the third position with 110.5 million tonnes, highlighting its growing role as a major exporter.

Among developed economies, the United States (91.0 million tonnes) and France (49.3 million tonnes) maintain significant shares; Canada (33.8 million tonnes) continues to play a crucial role as a reliable wheat supplier in international trade. In South Asia, Pakistan ranks seventh with 28 million tonnes, telling its importance for regional food security. Turkey and Ukraine, producing 25.5 million tonnes and 23.4 million tonnes respectively and are also exporters. Germany contributes 19.5 million tonnes, making it the tenth-largest producer globally.

Table 3.1: Leading Wheat Producers Worldwide (2022–23)

Rank	Country	Production (000' MT)
1	China	136,590
2	India	134,300
3	Russia	110,554
4	United States	91,000
5	France	49,314
6	Canada	33,824
7	Pakistan	28,000
8	Turkey	25,500
9	Ukraine	23,400
10	Germany	19,500

Source: FAO STAT, 2022

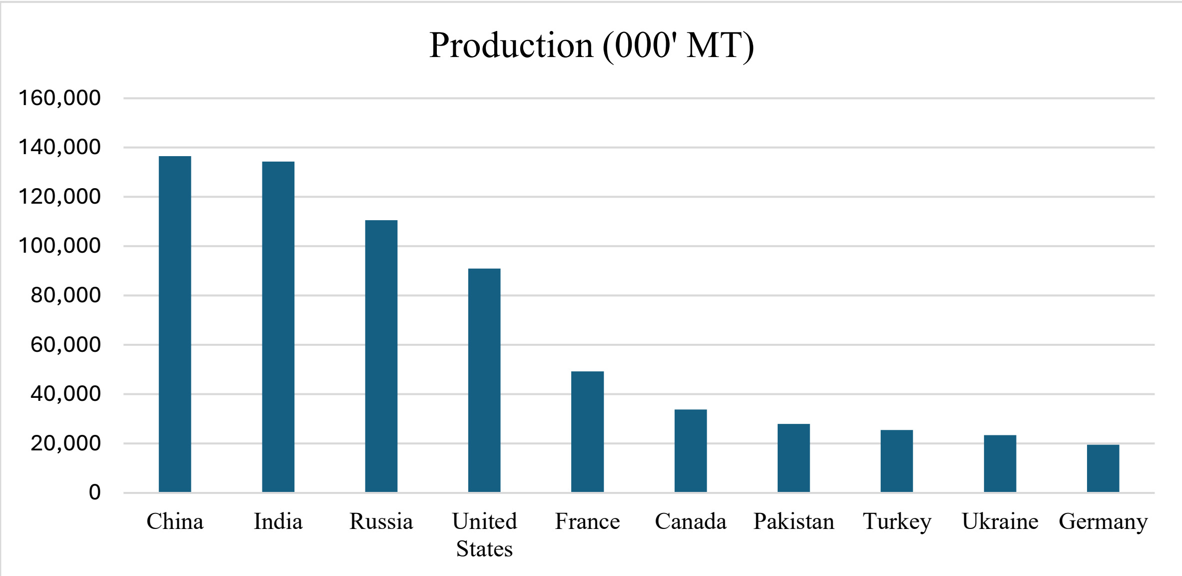

Fig.1: Leading Wheat Producers Worldwide (2022–23)

3.2 Area under Wheat Cultivation

Table 3.2 presents the trend in area under wheat cultivation across India, Himachal Pradesh, and Kangra district. At the national level, wheat acreage has largely remained stable, varying between 39 to 45 million hectares during the last two decades. A marginal decline was observed after 2015-16, though the area again improved in 2022-23, reaching 41.40 million hectares. In Himachal Pradesh, wheat area has shown more variation, moving from 366.50 thousand hectares in 2001-02 to 319.47 thousand hectares in 2022-23. This reduction reflects a gradual shift of land towards horticultural crops and other remunerative enterprises. In Kangra, the area under wheat has also been consistently declining, from 79.6 thousand hectares in 2001-02 to only 66.8 thousand hectares in 2022-23, indicating pressure on land resources and diversification away from wheat cultivation.

Table 3.2: Area under Wheat in India, Himachal Pradesh and Kangra

('000 hectares)

Year	India	Himachal Pradesh	Kangra
2001-02	44,904	366.50	80.10
2002-03	41,176	366.50	78.90
2003-04	42,593	363.40	77.30
2004-05	41,907	369.80	76.50
2005-06	43,660	358.45	75.20
2006-07	43,814	362.25	74.10
2007-08	43,914	366.59	73.80
2008-09	45,537	360.07	73.20
2009-10	41,918	352.52	72.60
2010-11	42,862	357.24	72.00
2011-12	44,006	355.87	71.50
2012-13	42,754	354.27	71.00
2013-14	44,136	371.06	70.20
2014-15	44,111	330.38	69.80
2015-16	41,466	341.05	69.20
2016-17	40,220	338.28	68.90
2017-18	39,651	342.68	68.50
2018-19	39,319	319.00	68.10
2019-20	41,357	319.10	67.70
2020-21	41,125	333.15	67.40
2021-22	40,459	320.22	67.00
2022-23	41,401	319.47	66.80

Source: Directorate of Economic & Statistics, Government of Himachal Pradesh (2022-23), Statistical Abstract of Himachal Pradesh; Ministry of Agriculture & Farmers Welfare, Government of India (2022)

3.3 Production of Wheat

As presented in Table 3.3 the production trend showed a steady increase in wheat output at the national level. From 72.77 million tonnes in 2001-02, India's wheat production rose gradually to 113.50 million tonnes in 2022-23, reflecting significant growth largely driven by productivity improvements. In Himachal Pradesh, production fluctuated more noticeably. It increased from 637.07 thousand tonnes in 2001-02 to a peak of 685.44 thousand tonnes in 2013-14, before showing a slight decline and settling around 600–620 thousand tonnes in recent years. Kangra district, though smaller in scale, also displayed moderate variability. Output rose from 119.5 thousand tonnes in 2001-02 to 137.4 thousand tonnes in 2022-23, but the pace of increase remained slower than the national trend, largely due to stagnating or declining sown area despite gradual improvements in yield levels.

Table 3.3: Production of Wheat in India, Himachal Pradesh and Kangra

('000 tonnes/MT)

Year	India	Himachal Pradesh	Kangra
2001-02	72,766	637.07	119.5
2002-03	65,761	495.56	112.4
2003-04	72,156	496.56	121.8
2004-05	68,637	687.45	118.9
2005-06	69,355	365.88	123.5
2006-07	75,807	596.49	125.6
2007-08	78,570	562.01	126.2
2008-09	80,679	381.18	124.9
2009-10	80,804	414.41	128.3
2010-11	86,874	546.47	132.6
2011-12	94,882	629.09	130.8
2012-13	93,506	671.94	133.5
2013-14	95,850	685.44	129.6
2014-15	86,527	646.45	135.2
2015-16	87,000	667.62	131.4
2016-17	98,510	605.18	137.5
2017-18	99,870	598.32	134.6
2018-19	103,600	682.63	136.2
2019-20	107,860	627.96	132.8
2020-21	109,586	575.57	138.9
2021-22	104,000	642.24	135.6
2022-23	113,500	609.31	137.4

Source: Directorate of Economic & Statistics, Government of Himachal Pradesh (2022-23), Statistical Abstract of Himachal Pradesh; Ministry of Agriculture & Farmers Welfare, Government of India (2022)

3.4 Productivity of Wheat

The productivity trends presented in Table 3.4 indicate consistent improvements across India, Himachal Pradesh, and Kangra, though the extent of progress varies. At the national level, wheat productivity increased gradually from 1.62 MT/ha in 2001-02 to 2.74 MT/ha in 2022-23, reflecting the impact of high-yielding seed varieties, increased mechanization, and better input management. Himachal Pradesh also witnessed gains, with yields improving from 1.74 MT/ha in 2001-02 to 1.91 MT/ha in 2022-23. Despite this progress, productivity in the state remains below the national average due to agro-climatic challenges and the prevalence of fragmented landholdings. In Kangra district, productivity advanced from 1,492 kg/ha in 2001-02 to 2,056 kg/ha in 2022-23, experiencing increase in productivity. Although land constraints continue to limit large-scale expansion, the adoption of improved practices and high-yielding varieties has supported these gains. Even so, both Himachal Pradesh and Kangra continue to lag national productivity levels, indicating the need for region-specific interventions to close the gap.

Table 3.4: Productivity of Wheat in India, Himachal Pradesh and Kangra

Year	India (MT/ha)	Himachal Pradesh (MT/ha)	Kangra (kg/ha)
2001-02	1.62	1.74	1492
2002-03	1.60	1.35	1425
2003-04	1.69	1.37	1576
2004-05	1.64	1.86	1554
2005-06	1.59	1.02	1642
2006-07	1.73	1.65	1695
2007-08	1.79	1.53	1710
2008-09	1.77	1.06	1706
2009-10	1.93	1.18	1767
2010-11	2.03	1.53	1842
2011-12	2.16	1.77	1830
2012-13	2.19	1.90	1880
2013-14	2.17	1.85	1846
2014-15	1.96	1.96	1937
2015-16	2.10	1.96	1898
2016-17	2.45	1.79	1997
2017-18	2.52	1.75	1965
2018-19	2.63	2.14	1999
2019-20	2.61	1.97	1961
2020-21	2.66	1.73	2060
2021-22	2.57	2.01	2023
2022-23	2.74	1.91	2056

Source: Directorate of Economic & Statistics, Government of Himachal Pradesh (2022-23), Statistical Abstract of Himachal Pradesh; Ministry of Agriculture & Farmers Welfare, Government of India (2022)

IV. CONCLUSION

The study on area, production and productivity of wheat in India, Himachal and Kangra district brought/ put forth the following points: First, at national level the wheat acreage mostly remained stable, varying between 44,904 thousand hectares in 2001-02 to 41,401 thousand hectares in 2022-23 during the last two decades. In H.P., wheat acreage shown more variation moving from 366.50 thousand hectare in 2001-02 to 319.47 thousand hectares in 2022-23. While the area under wheat in Kangra district has also been consistently declining indicating pressure on land resources and diversification away from wheat cultivation. Secondly, at national level production trend appeared a steady increase in wheat output while; wheat production in Himachal Pradesh showed a fluctuating trend. It increased from 637.07 thousand tonnes in early 2001-02 to a peak of 685.44 thousand tonnes in 2013-14 before showing a slight decline and settling around 609.31 thousand tonness in 2022-23.Thirdly, productivity of wheat in Himachal Pradesh improved from around 1.74 MT/ hectares in 2001-02 to 1.91 MT/ hectares in 2022-23, though still lower than the national average which was 2.74 MT/hactares in 2022-23 that points to untapped potential through better irrigation, seed quality and mechanizations.And lastly, in Kangra district, the productivity advanced from 1,492 kg/ha in 2001-02 to 2,056 kg/ha in 2022-23 resulting in an increase in productivity over two decades. Himachal Pradesh (HP) and Kangra district generally lag behind national trends in wheat growth, showing slower increases or even declines in area, production, and productivity, primarily due to significant challenges like rain dependency, moisture stress, and less irrigation. Both Himachal Pradesh and Kangra continue to lag the national productivity levels suggesting that there is a need for region specific interventions to close this gap.

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Role of Major Institutions in Promoting Agri-Entrepreneurs in India

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***Abstract*— *Agri-entrepreneurship is a critical driver for innovation and sustainable development in India's agrarian economy. Supporting institutions such as government bodies, financial organizations, research institutions, and agricultural extension services play a pivotal role in fostering agri-entrepreneurship by providing technical know-how, funding, market access, and policy support. The study was done to assess the role of institutions in promoting agripreneurs This paper explores the multifaceted role of these institutions in empowering farmers and agripreneurs to adopt innovative practices, diversify their enterprises, and access value chains more effectively. Through case studies and policy analysis, the paper examines the impact of institutional support for entrepreneurship in enhancing productivity, addressing challenges such as market volatility, and promoting agribusiness models that contribute to rural employment and economic growth. The research underscores the importance of strengthening these institutions for incubation and capacity building; enhanced financial access; promote market linkages and value-chains; digital and climate-smart agriculture; regulatory ease and compliance support to create an enabling environment for agricultural entrepreneurship, ultimately leading to more resilient and competitive agricultural sectors in India.*

Keywords*— Entrepreneurship; Agribusiness Startups; Innovation in Agriculture; Technology Adoption, Agripreneurs; Market Linkages.

I. INTRODUCTION

Agriculture has long been central to India's economy, ensuring food security and rural livelihoods. Though its share of Gross Value Added (GVA) declined from about 35% in 1990–91 to 15% in 2022–23 (GoI, 2024), the sector continues to grow at around 4% annually (Ramakumar, 2024). Nearly 45–50% of India's workforce still depends on agriculture (Goldar & Aggarwal, 2024; Chandrasekhar & Kumar, 2024), underscoring its persistent socio-economic role amidst structural transformation.

Agri- entrepreneurship has become a key force for growth, innovation, and rural development. Driven by technology and market-oriented models, agri-entrepreneurs enhance productivity, diversify into agribusiness, and add value through processing, boosting incomes and reducing rural-to-urban migration. Startups in agriculture and allied sectors have risen from fewer than 50 before 2014-15 to over 7,000 in 2023 (IBEF, 2023) supported by government subsidies, credit, technical assistance, and policy reforms. This paper aims to bring out the role of different institutions in promoting entrepreneurship in agriculture besides focussing on innovations and challenges faced by them.

Innovation remains central, with adoption of precision agriculture, IoT, and biotech, along with digital platforms and eco-friendly practices in agri-business sector. Further, entrepreneurs are investing in rural infrastructure in the form of cold storage, logistics, processing, etc., and provide training, empowering youth and women while fostering inclusivity. These shifts, are further, strengthen food security, create jobs, and mark a transition from subsistence farming to a diversified, sustainable, and innovation-led agricultural sector, underpinned by economic liberalization and policy support.

The academic literature corroborates the significance of these institutional frameworks. Reviews of agri-entrepreneurship research emphasize the importance of formal institutions such as government and private institutions involved in extension and finance, and training centres, alongside informal systems like cooperatives and self-help groups (Dias, 2019). Empirical studies conducted in India reveal that entrepreneurial intent among agricultural college students and rural youth is significantly enhanced when institutional support—training, incubation, and financial linkages—is present (Amaran, 2025; Pan, 2024). Similarly, institutional profiling across Indian states has shown substantial heterogeneity in capacity and effectiveness, suggesting a need for stronger coordination among universities, NABARD, KVKs, ATMA, and private sector incubators (Kademani *et al*., 2024).

It was reported that entrepreneurship training, incubation, youth-focused programmes, and value-chain linkages have proven effective in diversifying incomes and modernizing agriculture in developing countries (FAO, 2022; World Bank 2024a, 2024b). For instance, FAO's initiatives to unleash the potential of young agripreneurs stress the necessity of combining skills training with access to finance (FAO, 2013), while World Bank-supported agribusiness projects in Assam and Uttar Pradesh illustrate how institutional interventions can strengthen farmer producer organizations and agri-clusters (World Bank, 2024a, 2024b). Comparative insights from Laos, where young agripreneurs' perceptions of institutional support have been studied, further emphasize the universality of these institutional needs in fostering agribusiness (Thephavanh *et al*., 2023). National institutions of repute —ranging from KVKs, ATMA, and NABARD to multilateral organizations—are critical drivers of agricultural entrepreneurship. Their roles in providing finance, extension, training, incubation, and market linkages not only promote self-employment and innovation but also contribute to broader rural transformation.

II. METHODOLOGY

The study employed a mixed-method approach**,** combining qualitative and quantitative analyses to assess the role of major institutions in promoting agri-entrepreneurship in India. The research was based on deductive / inductive secondary data collected from institutional reports (NABARD, ICAR, APEDA, and NITI Aayog), government documents, academic journals, and official databases such as IBEF, FAO, and World Bank reports, etc. including all agriculture sub-sectors. Deductive / inductive methods are adopted besides a qualitative case study approach to highlight success stories and institutional linkages of selected agri-startups. Data were compiled from official websites, published articles, and industry reports, and presented through graphical and tabular forms.

The study adopted a descriptive and analytical design, structured to examine institutional roles in financing, incubation, training, and policy facilitation. Comparative and trend analyses were used to evaluate the evolution and performance of institutional support mechanisms from 2010–2025. Quantitative data were analysed using trend and descriptive statistics to interpret the growth of agri-startups, funding patterns, and institutional outreach, and are presented in graphical and tabular forms. Qualitative insights were derived through thematic analysis of policy frameworks, institutional models, and entrepreneurial outcomes.

III. EMERGENCE AND GROWTH OF AGRI-ENTREPRENEURSHIP IN INDIA

Traditionally, Indian agriculture relied on smallholder farming with limited market access and high post-harvest losses, but the liberalization of the economy in the 1990s and subsequent policy shifts created space for private innovation. The major boost came after 2014 with initiatives such as Startup India**,** Rashtriya Krishi Vikas Yojana – Innovation and Agri-Entrepreneurship Development Programme (RKVY-RAFTAAR)**,** and the establishment of agri-business incubation centres, which encouraged youth participation in the sector. Under the government's RKVY, around 1,708 agri-startups received financial and technical support between 2019–20 and 2023–24, with Maharashtra (226), Karnataka (211), and Tamil Nadu (137) emerging as leading states, followed by Telangana, Kerala, and Uttar Pradesh (Global Agriculture, 2024). In addition, industry estimates suggest that India hosts more than 1,500 agritech startups as of early 2025, reflecting a strong private-sector ecosystem in digital farming, supply-chain solutions, and precision agriculture. These variations in reported figures arise from differences in definition—whether counting all startups in agriculture and allied sectors, those formally recognized by DPIIT, or those supported under government schemes—but the overall trend clearly shows India's agricultural innovation ecosystem scaling rapidly over the past decade. The parallel rise of digital technologies like AI, IoT, blockchain, and mobile applications—enabled agritech startups to address challenges in supply chains, financial access, precision farming, and direct farmer–consumer linkages (AgroSpectrum, 2025).

Investment flows from venture capital and corporate partnerships further supported scalability, with states like Maharashtra, Karnataka, and Tamil Nadu emerging as key hubs due to their stronger incubation ecosystems. As a result, the number of agri-startups in India surged to over 7,000 by 2024 (Fig.1), reflecting a structural transition from subsistence farming toward innovation-driven, market-oriented, and technology-enabled agri-entrepreneurship (IBEF, 2024). The trend indicates the rapid acceleration after 2015, coinciding with policy support, digital innovation, and rising investor interest. This growth further highlights the sector's role not only in addressing agricultural inefficiencies but also in driving rural development, employment generation, and sustainable food systems.

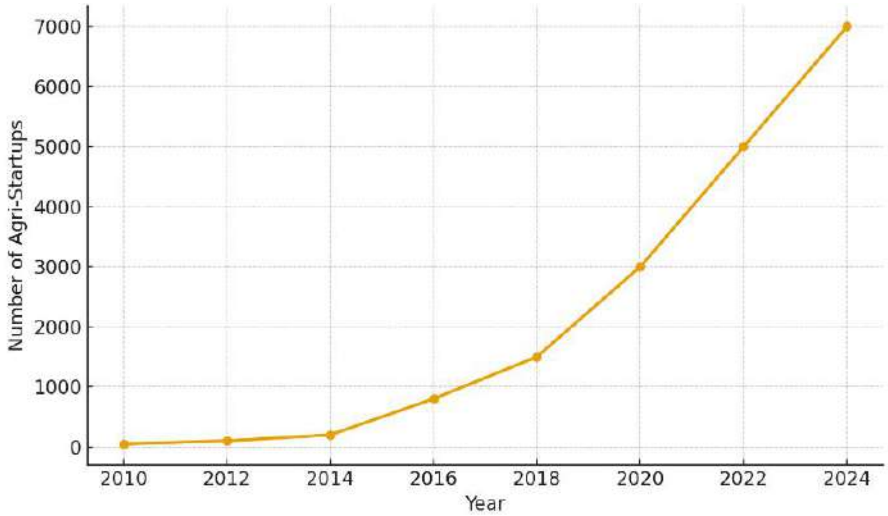

Fig. 1: Trends in agri-startup formulation in India during 2010-2024

Source: IBEF, 2024

IV. AGRI-STARTUPS IN INDIA: STATUS AND PERFORMANCE

There are many start-ups in agri and agri-businesses sector. There is a clear indication of youngsters leading the way. They make presence in areas such as marketing solutions, inputs supply, supply chain and logistics, precision agriculture, grading and quality control, food quality assessment, logistics solutions, capacity building, etc. (Table-1). A case of successful start-up is given below to learn the details of journey of the start-up.

Bharatrohan Airborne Innovation Pvt. Ltd., founded in 2017 in New Delhi by Amandeep Panwar and Rishab Chowdhary, is an agri-tech startup offering precision farming solutions using drone-based hyperspectral imaging and analytics. The company provides insights on crop health, soil conditions, and yield forecasts to help farmers make data-driven decisions. Its services include precision agriculture, real-time monitoring, soil mapping, and customized crop solutions supported by a skilled team of engineers, agronomists, and data scientists. Bharatrohan's technology enables early detection of pests, diseases, and nutrient deficiencies, optimizing fertilizer and pesticide use. This startup was incubated at a-IDEA (ICAR-NAARM) from 2016–19, and operates on both B2B and B2C models. It raised $36.8k each from a-IDEA and Upaya Social Ventures, securing a post-money valuation of $805k and earning recognition among the top global agri-startups. Financially, it recorded revenues of Rs 1 crore in 2019–21, a profit of Rs 0.1 crore in 2020–21, and reached a Rs 2 crore turnover in 2022. The company also won the Best Startup Award at the 2019 International Agriculture and Horticulture Expo. By offering affordable, easy-to-use UAV solutions, it supports smarter, more sustainable farming and strengthens farmer resilience. Like Bharatrohan, many other agri-startups are also working toward solving challenges faced by small farmers across India.

Table – 1: Sector-wise list of top agri start-ups in India

Sl.no.	Sector	Start-Up Names
1.	Capacity Building	Adrise India Pvt. Ltd., BharatAgri, cultYvate, Star Agribazaar Tech Ltd., Krushak Mitra Agro Services, Kshitiz Women SHG, Mandya OrganicFoods, Nurture Agtech (nurture.farm)
2.	Food Quality Assessment	AgNext Technologies, Praman.Ai, Agrograde, Saptkrishi Scientific, Ecozen Solutions, Fanidhar Agrotech, Freshokartz Agri Products, Vesatogo Innovations
3.	Marketing Solutions	AgriBolo, Farmers Fresh Zone, Farmpal, MeraKisan Pvt. Ltd., Organic Farmers Market, Waycool Foods & Products, BigHaat Agro Pvt. Ltd., Sahyadri Farms
4.	Logistics Solutions	Agrigator, Agrowave, Ninjacart, GramworkX Agrotech, Freshokartz, Star Agribazaar Tech, Farmpal, KisanSaathi
5.	Inputs Supply	Agriplex Pvt. Ltd., AgroStar, Jai Kisan, BigHaat Agro Pvt. Ltd., Fanidhar Agrotech, Vesatogo Innovations, EF Polymer Pvt. Ltd., Mandya OrganicFoods
6.	Renewable Energy Solutions	AgriVijay, Raheja Solar Food Processing, Ecozen Solutions, Apex Coco & Solar Energy, Han Agrocare LLP, Bastar Se Bazaar Tak, Soumya Foods Pvt. Ltd., Terraphilic Innoventures
7.	Grading & Quality Control	Agrograde, Praman.Ai, Saptkrishi Scientific, Star Agribazaar Tech, Siksha Infotech, GramworkX Agrotech, Freshokartz, Fanidhar Agrotech
8.	Precision Agriculture	BharatRohan Airborne Innovations, Agrotech Risk Pvt. Ltd., Cropin Technology Solutions, Fasal (Wolkus Technology), cultYvate, Waycool Foods & Products, Bhungru, Nurture Agtech
9.	Supply Chain & Logistics	Agrowave, Ninjacart, GramworkX Agrotech, Farmpal, Star Agribazaar Tech, Bhungru, Waycool Foods & Products, Sahyadri Farms

Source: NITI Aayog - Compendium of 75 Agri Entrepreneurs and Innovators, 2023

V. CHALLENGES FACED BY AGRICULTURAL ENTREPRENEURS

Though the start-up ecosystem looks rosy, agricultural entrepreneurs face various challenges that can hinder their efforts to develop and sustain successful agribusiness ventures including growth and profitability. These challenges stem from a combination of several factors like structural, economic, social, and environmental.

Some of the challenges faced by agripreneurs are:

- Limited access to funding: Incubators require significant financial resources to operate and support their startups, but securing funds can be difficult in regions with limited investment opportunities. It further makes it difficult for them to invest in their ventures, purchase necessary equipment, and scale their operations.
- Lack of skilled human resources: Finding experienced and skilled professionals to mentor and guide startups can be challenging in smaller cities and towns. On the contrary, ensuring access to quality inputs like seeds and fertilizers is another challenge, as counterfeit products can harm crop yields. Promoting sustainability and eco-friendly practices is difficult, given limited awareness and resources esp. among small farmers. Skilled labour shortages, particularly as rural youth shift to non-agricultural sectors, and migration to urban areas exacerbate operational difficulties.
- Infrastructure and connectivity issues: Inadequate rural infrastructure, including transportation, storage, and processing facilities, limits the agripreneurs' performance. Access to high-speed internet, reliable electricity, and other basic infrastructure can be inconsistent in some parts of the country, making it difficult for incubators and startups to operate effectively.
- Limited access to markets: Many startups struggle to scale their businesses due to limited access to markets beyond their local region. They are more vulnerable to price volatility, which affects income stability. Establishing market linkages and adding value through processing can be especially tough for small entrepreneurs, who also face stiff competition in both domestic and international markets.

- Regulatory challenges: Startups often face regulatory hurdles that can impede their growth. This includes issues related to licensing, permits, and compliance with local laws and regulations. Fragmented landholdings complicate efforts to achieve economies of scale, while complex regulatory frameworks and changing policies add administrative burdens. Agriculture's inherent risks, such as weather, pests, and diseases, further exacerbate uncertainty, with entrepreneurs lacking adequate risk mitigation tools and insurance.

Besides, entrepreneurs also lack access to timely agricultural information and extension services, hindering informed decision-making. Navigating institutional support is often complex, with many agripreneurs are unaware of the available resources.

VI. INSTITUTIONS SUPPORTING ENTREPRENEURSHIP IN AGRICULTURE

Institutional support is very critical to groom the entrepreneurs for establishing their start-ups. These institutions include government departments/bodies, financial organizations, research centres, educational institutions, incubation centres, Private organizations, MNCs, etc. (Table-2). They act as catalysts for innovation and sustainability in agriculture and allied areas by providing essential resources, financial assistance, technical know-how, knowledge, and market linkages. Institutional support in fostering agri-entrepreneurship and driving innovation within the sector in various forms, including:

- Financial assistance: Grants, subsidies, loans, and equity investments
- Technical expertise: Training, workshops, extension services, and business advisory support
- Infrastructure development: Building markets, cold storage facilities, and transportation networks
- Policy and regulatory reforms: Creating a conducive environment for entrepreneurship through regulations and incentives

Besides, they also offer training programs, access to credit, technology adoption, and policy support, thereby empowering entrepreneurs to scale up operations and improve productivity. Thus, their role is crucial in enhancing rural livelihoods, promoting agribusiness startups, and driving economic growth in India's agriculture sector.

Table-2: Institutions supporting entrepreneurship in agriculture

Category	Institutions	Provisions
Government organizations (both central and state)	SFAC, APEDA, NIF, KVKs, NHB, NSDC, T-hub We-hub, MSME	Grants, free or low fee incubation & acceleration process; low priced debt funds & seed funds
Research organizations	i) ICAR-ABI ii) SAUs iii) DBT iv) DST v) Despande Society vi) IITs vii) IIMs	i). Technology development and commercialization ii) Technology Co-development iii) Access to Laboratories iv) Researchers and Students taking start-ups
Investors	Angel investors, venture capitalists, private institutions, high net- worth individuals (HNIs), etc.	Investment
Lending institutions and Bankers	NABARD, PSBs like SBI, CBI, and also PVT banks	Loans and investment
Private Institutions	NGOs, Private labs, etc.	Investment, capacity building

6.1. Government Organizations

The central government has conceptualized innovative StartupIndia programme in 2016 to promote entrepreneurship across the sectors including agriculture. Since then, many entrepreneurs entered into start-up ecosystem with their innovative ideas. The following are the organizations involved in agri-entrepreneurship promotion in India.

- National Bank for Agriculture and Rural Development (NABARD) provides refinance option for banks to promote agriculture and rural development. It has promoted Self-Help Groups in India SHG-Bank Linkage Programme (SHG-BLP). As of 2023–24, India had 1.44 crore SHGs with bank deposits and 77.4 lakh SHGs credit-linked, channelling loans worth over ₹2.09 lakh crore (NABARD, 2024a, 2024b). Such access to microfinance has enabled rural households, particularly women, to invest in agri-based enterprises and diversify income sources (Pandhare, 2024). Further, NABARD extends support through capacity-building programmes, Rural Business Incubation Centres (RBICs), and commercialization of agri-technologies (NABARD, 2025).

- Small Farmers' Agri-Business Consortium (SFAC) is dedicated to supporting small and marginal farmers in forming and managing agri-business enterprises. It helps farmers access markets, technology, and credit, and provides training and capacity-building support to enhance their entrepreneurial skills.
- Agricultural and Processed Food Products Export Development Authority (APEDA) focuses on promoting agricultural exports from India. It supports agricultural entrepreneurs by facilitating market access, providing quality certification, and promoting value-added agricultural products for export.
- National Innovation Foundation (NIF) encourages grassroots innovations and inventiveness in agriculture. It identifies and promotes innovations by rural entrepreneurs, providing them with intellectual property rights and financial support to scale up their inventions.
- Krishi Vigyan Kendras (KVKs) are agricultural extension institutions supported by Indian Council of Agricultural Research (ICAR), NGOs and State Agricultural Universities (SAUs). ICAR coordinates a network of approximately 731 Krishi Vigyan Kendras (KVKs) across the country, which function as local hubs for vocational training, skill development, technology demonstrations and dissemination, and enterprise incubation (ICAR, 2024; PIB, 2025). These KVKs have been instrumental in motivating youth and women farmers to adopt entrepreneurial activities such as seed production, dairy processing, food processing, and horticulture-based enterprises, etc.
- National Horticulture Board (NHB) supports horticultural entrepreneurs by providing financial assistance, market linkages, and infrastructure development. It aims to boost fruit and vegetable production and processing.
- National Skills Development Corporation (NSDC) collaborates with various agricultural organizations to provide skill development programs for the rural youth. It offers training and certification in various agricultural and agri-business sectors, making them job-ready or ready to start their own enterprises.

6.2. Research Organizations

The government research organizations play a significant role in promoting agri-entrepreneurship by supporting innovation, incubators, and start-up funding in agri-tech. The details are as below:

(i) The ICAR, which functions Ministry of Agriculture and Farmers Welfare, Government of India, is the nodal agency for agricultural research, education and extension system in the country. Around 113 ICAR institutions develop technologies in agriculture, animal sciences, fisheries and veterinary and other allied disciplines. These institutions have state-of-the-art research lab facilities covering all components of agriculture and its allied activities. The technologies developed at ICAR labs have been commercialized for wider reach through entrepreneurship development. Besides, eleven regional Agricultural Technology Application Research Institutes (ATARI) located across the country are mandated to monitor, review and coordinating the KVK system besides play a vital role in strengthening agricultural extension research and knowledge management by promoting entrepreneurship.

(ii) The State Agricultural Universities (SAUs), which are around 79, conduct research, extension, and education in agriculture with focus on the respective State. They play a critical role in disseminating improved agricultural practices, technologies, and knowledge to farmers and budding agricultural entrepreneurs. They are encouraging the agricultural undergraduates to be entrepreneurs through awareness, incubation facilities.

(iii) Besides, the Department of Biotechnology (DBT), Government of India, supports agri-entrepreneurship by fostering biotech innovation, funding startups, and enabling technology translation from lab to farm. DBT’s autonomous arm Biotechnology Industry Research Assistance Council (BIRAC) offers grants, proof-of-concept funding, and equity-support such as via seed funds and schemes like “High-Performance Bio-manufacturing for Climate-Resilient Agriculture” to agritech startups and SMEs. Infrastructure support is also provided via Biotech Parks and Incubation

Centres across the country, giving early stage ventures lab space, equipment, and linkages to industry & academia.

(iv) The Department of Science & Technology (DST), Government of India, through its National Initiative for Developing and Harnessing Innovations (NIDHI) umbrella program nurtures ideas and prototypes through schemes such as NIDHI-Seed Support and accelerators, helping entrepreneurs turn science-based agri ideas into viable businesses implementing through various incubation centres like a-IDEA, IIT-Kanpur, ICRISAT, etc.

(v) The Atal Incubation Mission (AIM), under NITI Aayog, Government of India, aims to foster entrepreneurship and innovation across India. It supports the establishment of world-class incubation centres called Atal Incubation Centres (AICS) that nurture start-ups by providing mentorship, funding, and infrastructure in diverse sectors. Through this initiative, the government seeks to build a robust ecosystem for innovation-driven enterprise.

(vi) The Ministry of Agriculture launched the RKVY-RAFTAAR (Rashtriya Krishi Vikas Yojana - Remunerative Approaches for Agriculture and Allied Sector Rejuvenation) scheme which focuses on promoting innovation and entrepreneurship in the agriculture sector. It extends financial support, incubation facilities, business mentoring to agri-startups, and encouraging youth participation through RAFTAAR centres.

Thus, research organizations launched several programmes to encourage and promote entrepreneurship in agriculture directly by providing lab access, incubation facilities, providing platform for financial access, technical know-how, funding and networking facilities, etc.

6.3. Investors

Funds are life and breath to the start-ups. The innovative ideas turn into ventures only with right amount of funding at the right time. Investors play a crucial role in entrepreneurship development by providing this necessary financial support for start-ups to innovate and grow. Through venture capital, angel investing, and incubator programmes, investors help transform ideas into successful businesses.

(i) Angel investors / High net-worth individuals (HNI) investors provide early-seed proof-of-concept funding. The amount typically in the range of tens of lakhs up to a few crores. Angels and HNIs (often via networks like Indian Angel Network or LetsVenture) provide early seed funding.

(ii)Venture capitalists - They invest more substantially in agritech /foodtech /climate-smart agriculture to the tune of around US$130-150 million. Many growth- and early-stage startups have raised collectively over US$2 billion in past few years. Dedicated VC firms flows into Indian agri-foodtech reached hundreds of millions annually. Over 160 agritech startups raised collectively over US$2 billion between Jan 2020 and mid-2025 through around 246 deals. Growth-stage startups got US$1.59B in about 60 deals; early stage had around US$500M in around 186 deals.

(iii) Public funding / government programmes - The Government of India runs large programmes to spur agribusiness entrepreneurship in terms concessional finance, credit-linked subsidies and fund-of-funds support. The schemes include Agriculture Infrastructure Fund (AIF) which provides a ₹1,00,000 crore financing window for farm-gate infrastructure; PM Formalisation of Micro Food Processing Enterprises (PM-FME) which has an outlay of about ₹10,000 crore for micro food processors; and the SIDBI-managed Fund of Funds for Startups (FFS) has a ₹10,000 crore corpus to back AIFs that invest in startups. For promoting agri-entrepreneurship promotion among the agriculture and allied disciplines graduates, the government of India has started Agri Clinics and Agri-Business Centres (ACABCs) scheme in 2002. Through this scheme, the prospective agripreneurs are being trained besides enabling them for fund raise. They are provided hand-hold support till they are into the market with their innovative services/products in agriculture, especially in rural areas.

Thus, the investors, besides providing investment, offer mentorship, industry connections, and strategic guidance to entrepreneurs. Their involvement boosts job creation, economic growth, and the overall start-up ecosystem in India.

6.4. Lending Institutions and Bankers

The nationalised banks are mandated to fund entrepreneurs under government schemes meant for the purpose. A special fund is allotted for start-ups and entrepreneurship development in budget with annual increase of allocation.

Apart from NABARD, several public sector undertakings and private banks have invested in agri-entrepreneurship endeavours.

6.5. Other Stakeholders

Besides government and research organizations, investors and banking system, there are other players who are playing their contributory role in promotion of entrepreneurship in agriculture. Some of them are:

(i) Non-Governmental Organizations (NGOs): At the grassroots level, many NGOs are dedicated to empowering farmers and agricultural entrepreneurs by building their capacities and introducing sustainable farming methods. Illustrating this approach, the Deshpande Center for Social Entrepreneurship & Sandbox Hubballi (an initiative of the Deshpande Foundation) runs impactful programs—including Social Entrepreneurship Bootcamps, Idea2Impact, and Entrepreneur-in-Residence—that systematically nurture and support local entrepreneurs.

(ii) Private companies and their CSR verticals are playing their role to promote entrepreneurship in agriculture. Companies such as Samunnati, Glaxo, IKP Agri-Business Incubator, Indigram Labs Foundation, and Jain Agri Park have made impactful contribution.

(iii) Farmer Producer Organizations (FPOs) play a pivotal role in fostering agri-entrepreneurship in India by empowering small and marginal farmers, who make up 85% of the farming community. By collectivizing producers, FPOs tie up and do business with start-ups. For example, Immersion programme of a-IDEA brings together FPOs/FPCs, farmers and startups incubated in a-IDEA to showcase innovations, support networking, and explore collaborations. Its main aim is to connect FPOs/FPCs with agri-startups to address challenges in markets, technology deployment, value-addition, and access to resources like finance, improving both startup scaling and FPO efficiency.

Overall, other stakeholders are playing their might to transform traditional agriculture into a dynamic, market-driven sector, positioning farmers as key players in India's evolving agri-business landscape.

VII. INCUBATORS' SUPPORT FOR AGRICULTURAL ENTREPRENEURSHIP

Incubators or Incubation centres provide mentoring, resources, and access to networks to help agripreneurs develop and launch their ventures. From Ideation to market launch, typically incubation period lasts from six months to one year with exception to deep-tech start-ups. India has witnessed the emergence of several agribusiness incubators and startup accelerators that play a significant role in fostering innovation and supporting agripreneurs (Table-3) which are listed below:

Table-3: Incubators supporting entrepreneurship in agriculture

Category	List of some lead incubators
Government Higher Education organizations (both central and state)	IITs; IIMs; JNTU, Hyderabad TBI; Central Universities, respective State Hubs, etc.
Research organizations	ICAR-ABIs; SAUs; DBT; DST; ABI Center at ICRISAT, etc.
Private organizations (Managed by private entitles & running in PPP mode)	TiE AgriTech, Jain Agri Park (JAP), IKP Knowledge Park, Indigram Labs Foundation (ILF; Walmart Vriddhi Supplier Development Programme, TiE AgriTech Agri-Techies Nest Foundation, LVPEI BioNEST, Glasco; MLR Education Foundation - Technology Business Incubator (MLRIT), Aditya Global Business Incubator, Grameena Incubation Centre, Andhra Pradesh Innovation Society supports AP Innovation Centre for Agriculture, Foundation for Innovators in Science and Technology - Agriculture Innovation Centre, ICFAI Foundation for Higher Education Innovation and Entrepreneurship Council, UnLtd India (Hyderabad),

These incubators provide platform for agricultural entrepreneurs to develop their ideas, access resources, and receive mentorship. Incubators and programmes offer a supportive ecosystem for agricultural entrepreneurs and startups in the country. They provide mentorship, funding opportunities, access to a network of experts, and a platform for innovation and growth in the agribusiness sector. Entrepreneurs interested in agribusiness should explore respective resources to help develop and scale their ventures. For example:

ICAR – TBIs: ICAR's Technology Business Incubation (TBIs) / Agri-Business Incubation (ABIs) Centres are specialized platforms established to promote entrepreneurship and support startups working specifically in agriculture and food sectors (Table-4). These incubation facilities aimed at turning agricultural innovations and technologies developed in research institutes into viable commercial ventures. By fostering the commercialization of agricultural technologies developed by ICAR institutes, TBIs bridge the gap between research, industry and market.

One such prominent incubator is Association Association for Innovation Development and Entrepreneurship in Agriculture (a-IDEA) set up at ICAR-NAARM in 2014 and is supported many organizations like NABARD, DST, DBT, etc. The TBI is supporting over 300 agri-startups in various stages of development.

Table-4: Prominent Agri-business Incubation Centres in ICAR

Sl. No	Incubation centre	Host institute	No. of start-ups incubated
1	a-IDEA	ICAR-National Academy of Agricultural Research Management, Hyderabad	> 300
2	Nutrihub	ICAR-Indian Institute of Millets Research (IIMR), Rajendranagar, Hyderabad	>200
3	Pusa Krishi	ICAR-Indian Agricultural Research Institute (IARI), New Delhi	> 200
4	CIRCOT ABI	ICAR-Central Institute for Research on Cotton Technology, Mumbai	16
5	CTCRI ABI	ICAR-Central Tuber Crops Research Institute	~10
6	CIFE ABI	ICAR-Central Institute of Fisheries Education, Mumbai	148
7	NaAViC	ICAR-National Institute of Veterinary Epidemiology & Disease Informatics (NIVEDI), Bengaluru	~ 11
8	NRRI ABI	ICAR-National Rice Research Institute (NRRI), Cuttack	~ 19
10	NRC Meat - ABI	ICAR-National Research Centre on Meat (NMRI), Hyderabad	63

Source: *respective ICAR websites

VIII. ROLE OF OTHER STAKEHOLDERS

8.1. Value-chain players

Supply-chain and market players form the operational backbone of the agri start-up ecosystem in India. They include aggregators, processors, logistics providers, cold-chain operators, input suppliers, exporters, and large retail/e-commerce companies. These stakeholders connect farmers and agri start-ups to wider markets, reduce inefficiencies in procurement, and add value through sorting, grading, and packaging. They also help with price discovery, working-capital management, and post-harvest loss reduction by offering cold-storage and efficient transportation. For start-ups, such players provide not only access to markets but also credibility, technical know-how, and financial linkages that enable scaling.

8.2. Regulatory Bodies

Agri start-ups operate within national and international quality and safety frameworks. The regulatory bodies like FSSAI, APEDA, DGFT, NABL, BIS, etc., enables agripreneurs with the suitable licenses. The FSSAI is central for licensing and food safety compliance, while APEDA governs agricultural and processed food exports, organic certification National Programme for Organic Production (NPOP), and export promotion. The DGFT issues Import-Export Codes (IEC), essential for cross-border trade, and the BIS sets machinery/product standards. In addition, NABL accredits testing labs to certify food safety and quality parameters. These regulatory frameworks not only protect consumers but also allow Indian agri-products to compete globally, giving start-ups confidence in their market entry and export readiness.

8.3. Consultants

Consultants play a crucial role in helping agri start-ups navigate complex compliance and certification requirements for domestic and export markets. The services include company registration, GST, DGFT's Importer Exporter Code (IEC) for cross-border trade; and FSSAI licensing for food-related activities; RCMC and APEDA registration for Exporters of products; while also guiding businesses through certifications such as HACCP, ISO 22000 for pesticide residue and quality compliance; and organic certifications under NPOP. Further, they also help in connecting to all the players in the ecosystem such as liaising with bankers, investors, supply chain players, government departments and other agencies and solve challenging and time-consuming issues confronting the entrepreneurs.

IX. CONCLUSION

Institutions have emerged as central actors in fostering agri-entrepreneurship in India, establishing an enabling infrastructure and empowering youth through finance, training, and technology. Agri-entrepreneurship is evolving beyond traditional farming into a transformative economic force, driven by technological adoption, institutional backing, and targeted policy support. Organizations such as NABARD, ICAR, APEDA, and KVKs have been instrumental in providing credit, incubation, capacity building, and market linkages. This institutional scaffolding has catalysed the exponential growth of agri-startups—from fewer than 50 before 2015 to over 7,000 by 2024—fuelled by government initiatives and private investment.

Despite this momentum, significant challenges remain, including persistent financing gaps, underdeveloped infrastructure, market volatility, climate vulnerability, and burdensome regulatory compliance. To address these barriers and sustain growth, a multipronged institutional strategy is recommended. First, incubation and acceleration mechanisms must be strengthened through intensive, one-on-one mentoring, enhanced infrastructure, and dedicated agri-focused programs. Providing seed funding and stipends to early-stage entrepreneurs will improve financial sustainability during the critical startup phase.

Second, financial and regulatory frameworks should be enhanced by mandating priority sector lending for agri-startups, offering tax benefits for corporate CSR activities supporting agri-entrepreneurs, and introducing tax incentives for entrepreneurs commercializing technologies to corporate buyers. Simplifying compliance processes will further reduce administrative burdens.

Third, fostering a collaborative multi-stakeholder ecosystem—involving government agencies, financial institutions, investors, NGOs, and industry bodies—is essential to co-create solutions, share knowledge, and leverage resources. Public-private partnerships can play a pivotal role in scaling innovations and bridging infrastructure gaps.

Finally, awareness and inclusion must be promoted through sensitization programs, competitions, and digital outreach to engage youth, women, and underserved regions. Together, these strategies will cultivate a supportive environment for agri-entrepreneurship, driving not only increased farmer incomes but also sustainable rural development and national food security. Strengthening these institutional foundations will ensure that agri-entrepreneurship continues to serve as a catalyst for equitable and resilient agricultural transformation in India.

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Clipping as a Productive Word-Formation Process in Contemporary English

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***Abstract*— *This paper explores the phenomenon of clipping, a dynamic word-formation process in modern English, using a corpus-based approach. A corpus of 150 clipped patterns was collected systematically in the context of three types of communication: informal communication, electronic communication, and professional communication. This phenomenon is categorized using four structural patterns: back-clipping, fore-clipping, mid-clipping, and complex clipping. The data indicate that back-clipping is the most dominant form, which accounts for 68%, showing significant variation in productivity depending on the type of communication. Phonological analysis shows that 87% of the back-clipped words preserve the major stress pattern of the source word, which is in line with the principles of prosodic optimization. There is a unique pattern of clipping in electronic communication, where a few instances, such as app, pic, blog, have gained cross-register acceptability and institutional acceptance. This paper proposes that the productivity of clipping is determined by the interaction of the phonological structure, usage, semantic transparency, and sociolinguistic factors.*

***Keywords*— clipping, corpus analysis, word-formation, morphology, register variation**

I. INTRODUCTION

Word formation is essentially about how languages expand their lexical resources in order to keep up with new modes of speech and talk. And in this regard, one of the stand-out ways in which new words are formed in modern English is clipping, shortening an existing word but preserving meaning and grammatical structure in an efficient, convenient package.

This research takes a detailed, corpus-driven approach to the topic of clipping, employing 150 instances of clipping from among three communicative contexts. There are three aims of the research:

(1) To chart the distribution of different instances of clipping across contemporary English;

(2) To examine the register distribution of clipping productivity;

(3) To identify the phonological and sociolinguistic constraints on the acceptability and conventionalization of clipped forms.

1.1 Theoretical Background: Clipping as a Word-Formation Process

The expansion of English word stock is made possible through the use of various word formation procedures; these can be classified as major and minor procedures. The major word formation procedures include suffixation, prefixation, compounding, blend forms, and word formation involving the generation of new forms using rule-based models. The minor procedures include non-compositional procedures such as reduction, rearrangement, or categorial transformation. Bauer (1983) classifies clipping as a minor procedure and describes it as a "subtractive procedure in which new items are formed by phonological truncation rather than morpheme addition."[2] Plag (2003) classifies clipping as "the systematic deletion of phonological material from pre-existing words," a minor procedure in word formation yet very productive in informal usage.[7]

Marchand (1969) highlights the subtractive over addition process of clipping, contrasting it with derivation. When clipped variants gain sufficient usage in speech and writing, lexicalization follows, with clipped variants becoming autonomous lexical entries rather than context-dependent shorten ages.[5] Crystal (2008) points out that clipping is mainly found in colloquial dialects, with the goal of achieving efficiency and speed in communication without sacrificing semantic transparency. The extent of conventionalization is quite different in various clipped variants: while "bike" (bicycle) is fully lexicalized with register-neutral status, "prof" (professor) is marked for its use in informal contexts.[4]

1.2 Structural Taxonomy of Clipping Types

The word Marchand (1969)[5] defines a structural taxonomy of clipping with four types of clipping, which are differentiated on the basis of the site of phonological clipping. Back clipping, the most productive type of clipping in the English language, is the removal of the final syllable(s) with the retention of the first stressed syllable, as seen in "ad" (advertisement) and "exam" (examination). The prevalence of back-clipping correlates with English's predominant trochaic stress pattern, wherein initial syllables frequently bear primary stress and therefore maintain greater perceptual salience. **Fore-clipping** operates in the opposite direction, removing initial syllable(s) while retaining final portions, as in "phone" (telephone) and "bus" (omnibus). This type, though less frequent than back-clipping, occurs regularly with words of Greek or Latin origin featuring unstressed initial syllables. **Middle-clipping**, also termed syncope, eliminates medial segments while preserving initial and final material, producing forms such as "flu" (influenza). This type is relatively rare due to constraints on syllable deletion that maintain morphological recognizability. **Complex-clipping** involves combinations of multiple truncation processes or the integration of clipping with other word-formation operations, as illustrated by "perm" (permanent wave). Bauer (1983) [2]notes that these categorical boundaries are not absolute; ambiguous cases and hybrid forms demonstrate that clipping operates along a continuum rather than through discrete, mutually exclusive categories.

1.3 Register Variation and Sociolinguistic Dimensions

Clipped forms exhibit sharp divisions according to the status of speech variety. From the point of view of colloquial speech, fridge, dorm, or gym are spontaneous, unobtrusive shortcuts within the flow of informal conversation. McArthur (1992)[6] traces such popularity from what they imply socially: "solidarity, being in-group, and the very immediacy of speech".

Digital communication turbocharged clipping, giving us app, pic, and convo, which verge on universals in computer-mediated communication. These gadget-anchored abbreviations have a way of spreading fast and often break out of their casual turf into wider acceptance.

Clipping is also common in professional and technical languages, though it perhaps more often adjusts to fit the needs of the specific field. Medical clipping-exam, lab, rehab-provides speedy inside-group shorthand. In academia, psych, bio, and chem clippings serve both economy and identity. Quirk et al. (1985) [8]note that many clippings have pushed the boundaries of their register, with words such as phone and plane shifting from informal toward neutral-or even formal-showing just how fluid and shifting the lines between registers can be.

1.4 Factors Governing Clipping Productivity

In a nutshell, it is a tangled web of linguistic and socio-linguistic forces that determines which words get clipped and which clipped forms stick. Phonological shape of a word is one major constraint: clipping preserves the stressed syllables because they are more salient and hence more easily recognized. Cannon (1987) [3]demonstrates that English clipping is drifting towards simple prosodic patterns-mostly one- or two-syllable units matching the English preferred word length.

How frequently a term is applied plays a huge role in the intensity of its clippings. High-frequency words are more susceptible to phonological trimming, as speakers seek to save time with terms they apply quite often. Semantic transparency applies as well: the clearer the relationship between the clipped form and the original word, the more it is accepted. For instance, "bike" from the term bicycle reads out as clear, while "flu" from the term influenza is not that transparent, which may make people wary of it, unless you already know the relationship of the clipping.

Other influences exist: peers, media promotion, and prescriptive attitudes shape the instances where clipped forms catch on. Algeo (1991) [1]remarks that most clippings meet initial resistance from prescriptivists who see clipping as a threat to "proper" language. But as the variant forms begin to show up more and more in younger speech and online, the resistance fades, and clipping comes to feel natural and can eventually find its way into dictionaries.

1.5 Research Gap and Study Objectives

Despite clear clipping typologies and observed productivity patterns, empirical work on clippings is scant for today's digital age English. Studies generally rested on dictionary entries or a few examples; there was a lack of corpus-based attempts at studying clippings systematically across various registers. Changes in clipping productivity and ways in which digital-origin clippings broaden their register continue to be underexplored. This paper aims to fill those gaps through a corpus-based analysis of 150 clipped forms drawn from three registers: informal conversation, digital communication, and professional discourse. The research explores the following:

(1) The quantitative distribution of clipping types in contemporary English;

(2) Register-specific patterns in clipping productivity;

(3) Phonological patterns in stress preservation and syllable structure;

(4) Factors influencing the acceptability and conventionalization of clipped forms.

II. METHOD

2.1 Research Design

The research takes a corpus-based approach to investigate the way clipping operates in modern English—as to where it appears with what degree of productivity. The research methodology combines a research paradigm based on number-driven analysis about the distribution of different clipping forms with a qualitative analysis of phonological features characteristic of certain social registers. The research consists of a data collection of 150 clipped forms that have been subjected to analysis based on three aspects: those of forming, location, and phonology.

2.2 Data Collection

Data collection was conducted in a systematic manner with three major sources ranging from December 2024 to January 2025. Sources vary in context, ranging from communication contexts:

- Informal conversation rate (n=60): This data is collected from online communities such as Reddit and X/Twitter using search keywords from general clipping examples (for example, “prof,” “exam,” “dorm,” “gym”). This dataset only included English-speaking natives aged 18-35 to represent general usage patterns for this dialect: informal English spoken by natives in their younger years.
- Digital communication register (n = 50): Online text messages from the internet forum sites of Reddit and specialized online forums, as well as text messages from instant messaging services and social media sites, were examined. This register represents the shorthand style of computer-mediated communication (CMC).
- Professional register (n = 40): The data consisted of professional vocabulary from the fields of medicine, academics, and technology, which were gathered from professional literature, online medical sites such as WebMD and Mayo Clinic, course catalogs, and technical manuals.

2.3 Classification Framework

Each clipped word was assigned into one of the structural types, as follows, based on Marchand’s (1969) [5]structural classification:

- Back-clipping (removing final elements, retaining initial elements; e.g., “ad” < “advertisement,” “exam” < “examination”);
- Fore-clipping (removing initial elements, retaining final elements; e.g., “phone” < “telephone,” “plane” < “airplane”);
- Middle-clipping (removing medial elements, retaining initial and final elements; e.g., “flu” < “influenza,” “fridge” < “refrigerator”);
- Complex-clipping (blending two or more clipping operations or other word formation processes; e.g.,

"perm" < "permanent wave," "email" < "electronic mail"). Ambiguities were resolved by checking etymological references.

2.4 Analysis Procedure

The following variables were measured: structural type (categorized on the basis of a four-fold typology), syllabic structure (number of syllables in the source form and the clipped form), stress pattern maintenance (maintenance of the primary stress position in the clipped form of the source word), register distribution (primary registers of occurrence in communicative situations), semantic transparency (level of semantic retrievability from the clipped form), and frequency measures (relative frequency in the sample data set). Statistical analysis was carried out on the data to reveal the distribution of clipping types with respect to the context, with a view to finding any systematic distribution of the phonological structure. Chi-square tests were used on the data to find the statistical significance of the distribution of the data with respect to the register distribution, with a significance level of $p < 0.05$.

III. RESULTS AND DISCUSSION

This section presents the results of the corpus analysis of 150 clipped forms and discusses these findings in the light of current morphological theory and research in sociolinguistics. It will be seen that the analysis reveals patterns in the productivity, register distribution, and phonology of clipping, supporting theoretical claims with evidence, as well as reflecting the particularities of English in the digital era.

3.1 Distribution of Clipping Types

An Analysis of clipped forms shows a hierarchical structure in the productivity of clipping. Back-clipping stands out as the most prominent structural form with a total of 102 instances or 68.0% of the data. Fore-clipping accounts for 27 instances or 18.0% of the data, while complex-clipping accounts for 15 instances or 10.0%. The middle-clipping form accounts for only 6 instances or 4.0% of the data.

Table 1: Distribution of Clipping Types in the Dataset

Clipping Type	Count	Percentage	Representative Examples
Back-clipping	102	68.0%	ad (advertisement), exam (examination), prof (professor), gym (gymnasium), lab (laboratory)
Fore-clipping	27	18.0%	phone (telephone), plane (airplane), bus (omnibus), chute (parachute)
Middle-clipping	6	4.0%	flu (influenza), fridge (refrigerator)
Complex-clipping	15	10.0%	perm (permanent wave), email (electronic mail), blog (weblog)
Total	150	100%	

The strong adherence to back-clipping (68%) follows Marchand's 1969 ordering and extends it into today's speaking practices. This is associated with two aspects of sound: the natural stress on every second syllable, which is typical of the English language, and maintaining perceptual distinctness. This is because the English language emphasizes the first syllable of native words and even borrowed ones that are well-integrated into their pronunciation. This is exactly what happens in back-clipping, where every other part is removed except the stressed beginning.

On a similar note, the limited usage of fore-clipping and middle clipping can also be inferred from the prosodic pattern of words. Fore clipping mostly takes place when a particular word has its starting syllable unstressed, often consisting of roots taken from Latin or Greek words. For example, telephone to phone or omnibus to bus. This removal of unstressed letters or parts often preserves the significance of the dominant part of the letter. Middle clipping generally barely takes place due to possible modification of its morphological pattern, creating ambiguity regarding its interpretation.

3.2 Register Distribution Patterns

A comparison Productivity for clipping differed significantly across the three registers analyzed ($\chi^2 = 18.42$, $df = 6$, $p < .01$). In the informal, chatty form, a high percentage of clipped variants occurred (40.0%, $n = 60$), compared to online communication (33.3%, $n = 50$), and professional discourse (26.7%, $n = 40$).

Table 2: Distribution of Clipping Types Across Registers

Register	Back-clipping	Fore-clipping	Middle-clipping	Complex-clipping	Total
Informal	45 (75%)	9 (15%)	3 (5%)	3 (5%)	60
Digital	30 (60%)	8 (16%)	2 (4%)	10 (20%)	50
Professional	27 (67.5%)	10 (25%)	1 (2.5%)	2 (5%)	40

Functioning in informal conversations, clipping is always eager to appear, and especially so is back-clipping, which occurs in around three-quarters of instances. Phrases such as prof (professor), dorm (dormitory), and gym (gymnasium) sneak into informal academic discourse as unmarked alternatives. Turning to online communication, the trends tend to be more clear, where complex-clipping occurs in around 20%—this is a much larger proportion than in other varieties. In formal discourse, fore-clipping is more prominent than others, occurring in about a quarter, and medical-related terms are behind the thrust.

There are those that are limited to specific contexts, in the sense that "prof" stays social, "dorm" and "gym" remain locked to the social register, while "lab" and "rehab" are maintained in the discourse of the medical register. However, "phone," "plane," and "bike" appear in all forms of contexts, adopting a generic form.

Such clipping patterns in terms of register demonstrate that morphological productivity in clipping is best understood by considering structure as well as other sociolinguistic factors. The professional register makes up only about 26.7% of the entire data, which represents around 40% in a non-professional setup—a detail which might uncover what clipping actually signifies in a social context.

Nevertheless, clipped variants are rather markers of solidarity, in-group membership, and immediacy. This links back to the findings by another researcher in 1992 about the social roles of colloquial language. Despite prof, dorm, and gym appearing no differently as clipped variants than register-unmarked variants such as phone or bike, they remain linkages within the context of relaxed academic environments. This implies acceptability can rely on more than pure sound.

Patterns of clipping associated with professionals demonstrate how clipping contributes to creating communities of specialized conversations. The clipping productivity of terms associated with medicine is remarkably large: lab, exam, rehab, and med – all of these demonstrate shorthand expressiveness. Nevertheless, other examples include phone, plane, bike, and these overpass different registers. These originally informal terms have long since been devoid of their negative connotations and are now neutralized by their usage over prolonged periods of time.

3.3 Phonological Patterns and Prosodic Optimization

The analysis of clipping based on phonology shows evident systemic patterns that reveal restrictions regulating clipping productivity, and analyzing 102 examples of back-clipping, it was found that 89, or 87.3%, preserved the position of major stress from the original word.

Table 3: Syllabic Structure of Clipped Forms

Syllable Count	Number of Forms	Percentage
Monosyllabic	87	58.0%
Disyllabic	54	36.0%
Trisyllabic	9	6.0%

The majority (94%) shortened by one or two syllables. Only 6% retained three, but that was typically the case when shortening further would have obscured or destroyed the meaning of the word.

The finding that 87% of back-clipped forms retain the primary stress position of the source word provides quantitative support for Cannon's (1987) [3]claim that English clippings adhere to prosodic optimization principles. This pattern demonstrates that clipping operates according to systematic phonological constraints rather than arbitrary truncation. In preserving the stressed syllables themselves, clipping maintains those aspects of words which are most perceptually significant in terms of their phonology. In shortening toward mostly one- and two-syllable words (about 94% of the data), it shows English prefers short patterns in word length. Such patterns are in keeping with unmarked English footing patterns, which suggests that clipping patterns are being adapted to preferred templates and are more to do with optimizing the phonology of words to fit preferred templates than purely to do with subtracting phonological objects. In this regard, it all suggests that morphological operations are circumscribed by considerations of phonological well-formedness and thus firmly slot clipping as part of an otherwise normal phonological system for English.

3.4 Digital Communication and Accelerated Conventionalization

In online communities, there was an attendant digital talk that had its own set of characteristic signs, determined by the possibilities afforded by computer-mediated environments. Looking at the evolution of digital-origin clip shortenings such as "app" for application, "blog" for weblog, and "pic" for picture, several patterns emerge:

Rapid standardization: The clipped forms were quickly adopted and became widespread within 5 to 10 years, and this contrasts with old clipped forms such as "phone," "plane," which took many years to become standard words.

Transitioning to other sectors: Take the digital clippings. They began with a casual online focus but soon found their place in other, more formal areas. Today, 'app' appears in business communication, academic writing, and even in large dictionaries (starting in approximately 2010). 'Blog' also demonstrates a parallel transition. It has become a word adaptable to a range of journalism or academic levels.

Increased use of complex clipping: Complex clipping is even more prevalent in digital communication, occurring 20% as much as it does in other registers, often in combinations that incorporate clipping, blending, and other combinations of word formation tricks, such as "email," "blog," and "podcast."

Such unique patterns emerge as the most conspicuous lesson of the research, which indicates the great potential of computer-mediated platforms in new word creation. The pace of the embrace of digitized clipping can be accounted for by the confluence of the following factors:

Frequency: Certain words occur with fabulous regularity on digital sites. Consider the example of the word "app" itself—thousands of instances occur daily worldwide, and this not only causes phonetic reduction but accelerates community familiarity with the shortened form as well.

Global accessibility: Unlike older clipped forms which traveled along local networks of speech, digital clips reach a global audience instantly. Such rapid attention accelerates a process of normalization as everyone in the world starts using and fossilizing identical forms around the same time.

Functional need: New technologies gave rise to new entities like "blog" and "email," which demanded new words. Here, new words did not only provide different expressions of existing ideas but also filled gaps in the vocabulary, leading to a quicker acceptance and institutionalization of the innovations.

Digital clipping across different registers opposes the traditional understanding of informality and clipping being inextricably connected to one another, as if digital communication were to introduce unique linguistic patterns as anticipated by Crystal (2008)[4]. Use of words such as "app" and "blog," for example, in formal business language as well as in academia illustrates how contemporary digital technology facilitates moving informal language innovations towards a register-neutral zone in a short time. This trend suggests that digital communication has emerged as a force competing with traditional prestige language to determine language standards.

3.5 Semantic Transparency and Acceptability

It was revealed that semantic transparency and register variability are interrelated. If a clipped form has a high level of semantic transparency, one that makes the relationship between the clipped and full forms apparent, then that form is generally accepted in a variety of registers.

High transparency forms (register-neutral):

- "bike" (bicycle) - morphological relationship clear
- "phone" (telephone) - phonological connection transparent
- "plane" (airplane) - semantic association immediate

Low transparency forms (register-restricted):

- "flu" (influenza) - historical relationship obscure to contemporary speakers
- "cab" (cabriolet) - etymological connection lost
- "bus" (omnibus) - Latin origin not recoverable from English phonology

This is clear in that it shows semantic retrieval is what influences the likelihood of clipping being widely accepted outside of informal talking. Opaque variations are marked as being informal, but transparent variations may become conventional in any number of communication situations. This is consistent with Algeo's argument[1] in 1991 about new morphology being at first resisted by prescriptivists, but being used and having meaning helps gain acceptance.

3.6 Theoretical Implications

The study feeds into ongoing debates about the place of clipping in word formation. Although Bauer (1983)[2]referred to clipping as a “minor” process, the high frequency and clear, patterned behavior evidenced here suggest that clipping functions as a productive morphological operation in contemporary English, particularly in casual and online speech.

The data point to a multifactorial view of morphological productivity that blends structural constraints-phonological wellformedness and prosodic ease-with sociolinguistic factors such as register suitability, social meaning, and how often a form appears. Clipping's productivity isn't something you can predict from sound rules or the meaning of the source word alone; it comes from the intersection of linguistic form, communicative purpose, and social evaluation.

Noticeably, stress patterns are retained to a great extent 87%, and the majority of forms tend towards optimal prosodic shapes 94% are one- or two-syllable. This demonstrates that even a simplified process operates within a bounded linguistic system. It challenges the idea of clipping as mere random abbreviation and instead places it within the standard phonological and morphological framework of English.

3.7 Limitations and Future Research Directions

First, the dataset (n=150) is modest. Larger corpora would produce more robust analysis.

Second, the study examined only written clipped forms. Phonetic and acoustic analysis of speech could reveal how clipping emerges from casual reduction. Third, while register variation was noted, individual sociolinguistic differences (age, gender, region, class) were not systematically studied. Fourth, the analysis was synchronic; diachronic tracking of clipping from emergence to lexicalization would clarify pathways of change.

Future research directions include:

1. Cross-linguistic comparison to test the universality of observed constraints.
2. Psycholinguistic studies on the cognitive processing of clipped forms.
3. Computational modeling of clipping patterns in large corpora.
4. Social media analytics to trace rapid conventionalization online.
5. Pedagogical research on how second language learners acquire and use clipped forms appropriately.

IV. CONCLUSION

This paper goes in-depth into the concept of clipping as a productive procedure which is currently practiced by the English language to construct new lexical entries, exploring the topic through the analysis of 150 examples found in different registers. The findings support theoretical propositions concerning the role of phonology, morphology, and sociolinguistics in clipping, while pointing to specific contemporary characteristics of the language of the digital age.

The data reveals that back-clipping is the most frequent type, constituting 68%, followed by fore-clipping at 18%, followed by complex-clipping at 10%, while middle-clipping comes fourth at 4%. The ranking matches the sound phonological patterns, particularly the prominence of a stress syllable in a focus-marked category. It is also important to note that a significant 87% of back-clipped variants retain the principal stress in the clipped word. This indicates that clipping is a principled phenomenon rather than a random process. This adds weight to the claim that it is a rule-based morphological phenomenon.

In the aspect of register, the variation in the distribution of clippings is quite evident. For instance, in the aspect of informal talk, the highest percentage of clippings is 40%, followed by digital communication at 33%, while in professional discourse, the percentage is 27%. Therefore, clippings can be seen as double-edged as they are used as quicker speech/typing assistance as well as social identity markers. In this regard, some clippings retain their connection to the context in which they are used as social markers within an in-group in informal contexts or as markers of technical know-how in professional contexts. However, other clippings tend to widen their scope to the extent that they are used in all contexts and in all kinds of discourse, as is the case of words like "phone", "plane", or "bike".

The study highlights how digital communication patterns are shaping the linguistic landscape. Terms born of digital life, such as "app," "pic," "blog," and "email," have made the journey from novelty to common usage in just 5 to 10 years, considerably faster than earlier slang or clippings did. This brisk normalization contrasts with the slow, decades-long uptake seen in the case of earlier words. The speed is linked to what computer-mediated communication enables: ultra-high usage frequency, instant global spread, clear meaning, and the practical need for new labels as technology creates new referents. The finding that digital talk exhibits a noticeably high rate of complex clippings, at about 20%, suggests that online platforms serve as hotbeds for linguistic experimentation, generating forms that can rapidly shake off their casual origins and achieve formal traction.

4.1 Theoretical Contributions

This research contributes to morphological theory in numerous ways.

Firstly, it provides empirical evidence for phonological structure, semantic transparency, and sociolinguistics influencing clipping productivity, along with effects of frequency. The data support a multifactorial model of morphological productivity that integrates structural linguistic constraints with socially situated language use.

Second, the study points out the importance of clipping as an ongoing fruitful method of word-formation in present-day English, in online communication in particular. Although the classical morphology considers it to be of limited scope, it is characterized by great productiveness and adaptability to communication needs, which makes one question the classification of this type of morphology.

Third, it has been found that there exists a definite phonological pattern regarding clipping, in particular as concerns stress and prosodic optimization. Such findings firmly locate clipping in a signal system in English phonology and morphology.

4.2 Final Remarks

Clipping shows the dynamic nature of language as a system simultaneously restricted by structural rules and responsive to communication requirements. As English continues to evolve in increasingly digitalized global contexts, clipping will likely remain a very productive method for lexical innovation, yielding forms that balance phonological naturalness, semantic transparency, and functional efficiency. The patterns reported in this study provide a foundation for future research tracking morphological change in real time, probing the cognitive mechanisms governing clipping creation and comprehension, and researching cross-linguistic variance in word-formation processes. By demonstrating how clipping occurs across multiple registers and communication situations, this research contributes to larger understanding of morphology as a systematic, adaptive, and socially placed component of linguistic knowledge.

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A Review on Manual Intra Weeders for Field Crops

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***Abstract*— *Weeds are one of the major constraints limiting agricultural productivity due to their rapid growth and competition with crops for nutrients, sunlight, water, and space. Effective weed control is therefore essential for improving crop yield, reducing production losses, and ensuring sustainable farm management. This review summarizes the different categories of weeders-manual, manually drawn, mechanical, inter-row, and intra-row and highlights their working principles, advantages, and limitations. Traditional hand tools such as the hoe, sickle, hand fork, and grubber weeder continue to play a crucial role in small-scale farming, while manual drawn weeders like wheel hoes and cono weeders offer improved efficiency and reduced drudgery. Mechanized solutions, including rotary weeders, power weeders, rotavators, and tractor-mounted cultivators, enable faster and more uniform weed removal across larger areas. Recent advancements focus on ergonomics, precision navigation, and automation through machine vision, robotics, and solar-powered systems. Together, these technologies contribute to sustainable weed management by reducing labor demand, minimizing herbicide dependence, and enhancing overall field efficiency. The review places special emphasis on manual intra-row weeders used in field crops due to their importance in small-scale and sustainable farming systems.*

***Keywords*— Weed management, Manual weeder, Mechanical weeder, Inter-row weeder, Intra-row weeder.**

I. INTRODUCTION

A weed is defined as any plant growing where it is not wanted [3]. It destroyed ideal environmental conditions which is required for optimal crop productivity. Since the beginning of crop production system and all through generation, waste plant growth among the planted crops has been the major task facing agriculturalists all generations. There is competition between the non-crop plant and crops for sunlight, soil water, space and soil nutrient, the non-crop plant/waste plant is known has weed [2]. In plant propagation and production cycle, weed removal is essential and similarly a tedious operation. It is therefore essential to control weed to reduce losses in production cost and improve crop yield. Poor weed control can result in over 50-70 % reduction in crop yield and one third of the cultivation costs is weed cost [4]. The damages caused by weeds can be severe in agricultural sector [14].

In India, weeds are one of the major biological constraints that limit crop productivity. A weed can be thought of as any plant growing in the wrong place at the wrong time and doing more harm than good [1]. Weeds grow far more quickly than crops do and if they are not controlled and maintained they may take over the entire field. Unfortunately, its sustainable nature will reduce crop productivity [2]. Most crops require that the field be kept weed-free during the first 4 to 6 weeks after planting to prevent serious yield losses from early season weed competition. Managing weeds effectively is one of the most crucial agricultural tasks. Weeds reduce crop productivity because they compete with plants for resources and nutrients [2]. Weeds reduce productivity, increase the cost of cleaning and overall, adversely affect the value of the land and thereby affecting the farmer's energy, time or money [19]. Weed control is an essential aspect of farm management, primarily because it has a detrimental impact on crop productivity and quality. There are several different types of weed control techniques, including mechanical, biological, cultural, chemical, and preventative [6,7]. Organic farming relies on the interactions between preventive measures and mechanical weed control while conventional farming heavily relies on herbicides [24]. There are various commercial mechanical weeders that employ the three physical weed management methods of Burying, Cutting, and Uprooting.

II. REVIEW OF EXISTING WEEDERS

Manual and mechanical drawn Inter-row Weeder Farmers typically substitute mechanical interrow weeding for herbicides. Row crops including vegetables, sugar beets, and cereal crops, among others, use it. The weeder's goal is to weed as much of the space as they can without harming the crop [23]. Different types of manual and mechanical drawn weeders discussed fallowing sections.

2.1 Common Types of Manual Weeders (Hand-held Tools)

1. Hand Hoe (Khurpi)

A small hand-held tool with a flat blade used for scraping, cutting, and uprooting shallow-rooted weeds. It is commonly used in vegetable beds, nursery plots, and smallholder farms because of its precision and ease of use shown in Fig.1.

2. Sickle

A curved-blade tool used for cutting tall weeds, grasses, and unwanted vegetation. It is effective for clearing field borders, bunds, and harvesting fodder weeds in mixed cropping systems shown in Fig.3.

3. Hand Fork

A three-or four-tined tool used for loosening soil around plants and removing weeds along with their roots. It is useful for orchards, flower beds, and home gardens shown in Fig.2.

4. Grubber Weeder

A hand tool with 3-5 curved tines used for loosening soil, uprooting weeds, and breaking soil crusts in vegetable beds, orchards, and nursery plots shown in Fig.4.

Fig 1: Khurpi

Fig 2: Hand fork

Fig 4: Grubber Weeder

Fig 3: Sickle

2.2. Manual Drawn weeders

Manual drawn weeders are hand operated tools designed to remove weeds by cutting, uprooting, or covering them. These tools are commonly used in small farms where mechanized equipment may not be available or practical [23]. They are particularly suitable for row crops like vegetables, cereals, and sugar beets because they can be easily adjusted to different row spacings [16].

Manual weeders are precise and do not damage crops. Modern designs, such as wheel hoes and adjustable handled weeders, reduce fatigue and increase efficiency [12]. However, manual weeding require a lot of labor and are less suitable for large farms.

Manual weeders also play an important role in organic and sustainable farming. By mechanically controlling weeds, they reduce the need for chemical herbicides, lowering production costs and supporting environmentally friendly practices [20]. Effectiveness depends on soil type, crop density, and operator skill.

2.3 Common Types of Manual Drawn Weeders

2.3.1 Wheel Hoe - A push-type tool with interchangeable blades for inter-row weeding vegetables and cereals.

2.3.2 Cono Weeder- A lightweight manual device used primarily in wetland paddy fields.

2.3.3 Push-Pull Weeder- A V-shaped blade that cuts weeds during forward and backward movement.

Fig 5: Wheel Hoe

Fig 6: Cono Weeder

Fig 7: Push-Pull Weeder

2.4. Mechanical weeders

Mechanical weeders are powered or tractor drawn implements that remove weeds over larger areas more efficiently than hand tools. They typically luse blades, discs, tines, or rotary mechanisms to cut, uproot, or bury weeds [4].

These machines allow farmers to weed faster and reduce labor requirements. Tractor mounted inter row cultivators are commonly used for crops such as maize, sugarcane, and cereals. The performance of these machines depends on factors like working depth, forward speed, and blade configuration to avoid crop damage [20].

For smaller plots, motorized walk behind weeders are widely used. These machines improve consistency and reduce operator fatigue while maintaining good weed control [10]. Mechanical weeders require higher initial investment and maintenance, which can be difficult for small farmers.

2.5 Common Types of Mechanical Weeders

2.5.1 Rotary Weeder Uses rotating blades or discs to cut and mix soil while uprooting weeds.

2.5.2 Power Weeder/ Walk-Behind Weeder Self-propelled machines used for small and medium farms.

2.5.3 Rotavator (Rotary Tiller) Performs weed control and soil pulverization simultaneously.

Tractor-Mounted Inter-Row Cultivator- Uses tines or sweeps to remove weeds between crop rows.

Fig 8: Rotary Weeder

Fig 9: Rotavator

2.6 Inter and Intra Row Weeders

Inter row weeders target weeds between crop rows. Intra row weeders remove weeds within the crop row. Inter row tools include rotary hoes, tined cultivators, and disc harrows. They are effective for many crops and tolerate small alignment errors [16]. Intra row tools, such as finger weeders and torsion weeders, require precision to avoid crop damage. They are useful during early growth or for widely spaced crop [20]. Recent advances combine inter and intra row weeding tools into integrated systems, including robotic and sensor assisted implements. These systems can selectively remove weeds, reduce chemical use, and improve overall efficiency [10]. However, intra row tools still face challenges such as cost, soil condition limitations, and residue management.

Recent developments in weeder technology focus on ergonomic improvement, precision guidance and sustainability. Ergonomic studies emphasize handle design, weight distribution, and posture optimization to minimize operator fatigue during prolonged manual weeding operations [8]. At the mechanical scale, smart weeders are being integrated with machine vision, GPS, and AI-based weed detection to achieve targeted control [18]. These systems distinguish crop and weed species using color, shape, and spectral features, allowing selective actuation of cutting tools or micro-sprayers. Moreover, hybrid weeders powered by solar-electric drives are being tested to reduce fuel consumption and carbon emissions [15]. Such innovations bridge the gap between manual precision and mechanized efficiency, promoting sustainable weed management practices that align with precision agriculture goals.

Fig 10: Finger Weeder

Fig 11: Disc Harrow

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Evaluation of Seedling Trait Responses to EMS-Induced Mutagenesis in Greengram (*Vignaradiata* (L.) Wilczek)

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Abstract**—** *The present study was conducted at the Department of Genetics and Plant Breeding, Acharya Nagarjuna University, Lab, Guntur, Andhra Pradesh, and at the Centre for Plant Molecular Biology, Osmania University, Hyderabad, during the period from February 2024 to April 2024. The greengram (Vignaradiata (L.) Wilczek) genotype WGG-42 was procured from ICAR–CRIDA, Santosh nagar, Hyderabad. Ethyl Methane sulfonate (EMS), obtained from HiMedia Laboratories Limited, Mumbai, India, was employed as the chemical mutagen for inducing mutations in greengram seeds.The analysis of variance (ANOVA) results revealed highly significant differences (p ≤ 0.01) among the treatments for all the studied seed germination and seedling traits. This indicates that EMS-induced mutagenesis caused considerable variation in the early growth and seedling performance of greengram.The seedling traits results revealed that the lower EMS concentrations (0.05-0.1%) have not exerted any harmful effects and, in some cases, slightly enhanced seedling growth and vigour. In contrast, moderate to higher EMS doses (≥0.2%) resulted in a gradual decline across all measured traits. An EMS concentration of 0.1% was identified as optimal for inducing genetic variability while minimizing injury. The observed traits showed a clear dose-dependent inhibitory response at higher EMS levels, highlighting the toxic effects of EMS when applied at higher concentrations. The findings indicate that EMS at lower concentrations is effective in generating genetic variability without causing substantial adverse effects on seed germination and seedling growth. In contrast, higher concentrations of EMS exert lethal and sublethal effects, resulting in reduced seedling establishment and diminished vigour.*

Keywords**— Greengram, Ethyl Methane Sulfonate, Induced mutagenesis, Seedling trait**

I. INTRODUCTION

Greengram or mungbean (*Vignaradiata* (L.) Wilczek) is a major pulse crop widely grown in the tropical and subtropical regions of Asia, Africa, and parts of South America. It belongs to the family Fabaceae, it is highly valued for its rich nutritional profile, short growth duration, and its capacity to improve soil fertility through symbiotic biological nitrogen fixation. Greengram seeds contain about 24-26% protein, 1-1.5% fat, and 60-65% carbohydrates, and are particularly rich in essential amino acids such as lysine and leucine. Owing to these attributes, mung bean serves as an important dietary protein source, especially in vegetarian diets (Kaur et al., 2023).Globally, greengram is cultivated on nearly 7 million hectares, with an annual production of around 4.5 million tonnes (FAO, 2023). Owing to its short duration of 60-75 days, minimal water requirement, and adaptability to marginal and rainfed environments, the crop has emerged as a climate-resilient legume of global importance (Rani et al., 2022). Furthermore, greengram contributes significantly to sustainable agricultural systems by enhancing soil fertility through effective biological nitrogen fixation, adding approximately 30-50 kg of nitrogen per hectare to the soil (Kumar et al., 2023).In India, greengram is grown across nearly all agro-climatic regions, occupying about 4.5 million hectares with an annual production of approximately 2.5 million tonnes and an average productivity of 550-600 kg ha^{-1} (ICAR-DARE, 2024). Rajasthan, Maharashtra, Madhya Pradesh, Karnataka, Tamil Nadu, and Andhra Pradesh are among the leading greengram-producing states. Owing to its short growth duration and low input demands, the crop integrates efficiently into diverse cropping systems, including rice-mungbean, maize-mungbean, and cotton-mungbean rotations (Singh et al., 2021). This wide adaptability has established greengram as a key component of sustainable and integrated farming systems.Despite its considerable nutritional and agronomic significance, greengram (*Vignaradiata* (L.) Wilczek) has yet to realize its full yield potential, largely due to the narrow genetic base of existing cultivars and the crop's predominantly autogamous nature. Being a self-pollinated species with a limited effective population size, the scope for natural recombination is minimal (Singh et al., 2021). Consequently, the genetic variability accessible through mutational breeding approaches such as EMS chemical mutagenesis remains highly constrained, resulting in stagnation of productivity improvements in recent decades.

Ethyl methanesulfonate (EMS) is a potent alkylating agent ($C_3H_8SO_3$) widely used as a chemical mutagen due to its high mutagenic efficiency and comparatively low physiological toxicity. EMS predominantly induces point mutations, particularly G:C → A:T transitions, by ethylating the O^6 position of guanine residues in DNA (Greene et al., 2019). This alkylated guanine mispairs with thymine during DNA replication rather than with cytosine, resulting in stable base substitution mutations that are inherited in subsequent generations.Although EMS mutagenesis has demonstrated considerable potential for creating useful genetic variability, integrated studies encompassing morphological, physiological, biochemical, and molecular assessments across multiple generations in greengram remain scarce. Most earlier investigations have been largely confined to M_2 populations, resulting in limited insight into the heritability and stability of induced traits in later generations. In this context, the present study is designed to systematically assess the effects of EMS-induced mutagenesis on seed germination, seedling parameters of greengram.

II. MATERIALS AND METHODS

The present investigation was carried out at the Department of Genetics and Plant Breeding, Acharya N.G. Ranga Agricultural University, Lam, Guntur, Andhra Pradesh and Centre for Plant Molecular Biology, Osmania University, Hyderabad during Feb, 2024 to April, 2024.The greengram (Vignaradiata (L.) Wilczek) genotype-WGG-42, obtained from ICAR-CRIDA, Santoshnagar, Hyderabad and thee ethyl methane sulphonate (EMS) was obtained from HIMEDIA Laboratory limited, Mumbai, India, was used as chemical mutagen to induce the blackgram seeds. To determine the optimal mutagen concentration, seeds soaked for 5 hours and were subjected to various EMS concentrations (0.05%, 0.1%, 0.2%, 0.3%, 0.4% and 0.5% and control (untreated). Keep the above seven sets in incubator shaker at 180 rpm at room temperature of (27 ± 1 °C) for 3hrs. After that, seeds were thoroughly washed under running tap water for 30 minutes to remove residual EMS. The treated seeds were sown in germination trays, and germination percentage and seedling survival were recorded after 7 days and 13th day. The LD_{50} value (concentration causing 50% reduction in germination) was calculated following the method of Konzak et al. (1965).

Seedling parameters recorded

Seed germination

Germination counts were recorded, after regulating the germination percentage of the control, beginning on the third day after sowing and continuing until the seventh day. The results were expressed as the proportion of germinated seedlings to the total number of seeds sown.

Seedling survival

Observation on survival was made on 30th day of sowing. Plants with at least two primary leaves above the cotyledonary leaves were considered as surviving. It was expressed as percentage of surviving plants to the total number of seedlings emerged.

Seed Germination

The requirements of seed germinations are carefully considered for optimal plant growth. This process is highly crucial that influence the quality and crop yield. Seed germination begins with imbibition of water. As the seed takes in water, it gets bigger and produces an enzyme that enhances the metabolic activity in the seed for breaking the endosperm to provide energy (Rani et al., 2013).

Seed germination rate

The seed germination rate depends on the genetic composition, environmental factors and morphological features. The rate of germination is beneficial for the estimation of the number of seeds for the provided area or the chosen number of plants. The germination capacity is denoted as the number of seeds for complete germination in a population (Baskin and Baskin, 2014).

Seed vigour

The measurement of seed quality with seed variability, germination rate, germination percentage and the seedling strength (Rajjou et al., 2012).

Survival rate

Survival rate is defined as the percentage of living crop seedlings against the total number of planted crop seedlings. The quality of the seed reduces with age and is correlated with the accumulation of genetic modification.

$$\text{Survival rate} = \frac{\text{Number of living seedlings}}{Total number of seedlings} \times 100.........(1)$$

Results and Discussions

The analysis of variance (ANOVA) revealed highly significant differences ($p \leq 0.01$) among the treatments for all the studied seed germination and seedling traits (Table 1). This indicates that EMS-induced mutagenesis caused considerable variation in the early growth and seedling performance of greengram.

Table 1. Analysis variation (ANOVA) for seed germination and Seedling traits in greengram under induced EMS mutagenesis

Source of Variation	DF	MSSQ				
		Characters				
		Seed germination%	Shoot Length (cm)	Root length cm	Seedling Vigor Index	Seedling Survival rate %
Treatment	7	873.81**	34.57**	3.42**	523039.44**	1047.61**
Error	16	116.667	0.379	0.00	16,459.41	236.83
C.D.		18.857	1.074	0.09	223.976	26.866
SE(m)		6.236	0.355	0.03	74.071	8.885
SE(d)		8.819	0.502	0.042	104.752	12.565
C.V.		14.243	6.132	1.511	15.865	19.839

Significant at: (p=0.05) and **: (p=0.01) level

For seed germination percentage, a highly significant difference (MSS = 873.81**) was observed among the treatments, suggesting that EMS treatments influenced the germination potential of seeds. Similarly, shoot length (MSS = 34.57**) and root length (MSS = 3.42**) also exhibited significant variation, implying differential response of seedlings to mutagenic treatment.The seedling vigor index (SVI) showed a highly significant variation (MSS = 523039.44**) among treatments, indicating that EMS-induced mutations affected overall seedling vigor through their influence on germination and seedling growth. Moreover, seedling survival rate (%) differed significantly (MSS = 1047.61**) across treatments, highlighting that mutagenic stress altered the ability of seedlings to establish successfully.The coefficient of variation (CV) ranged from 1.51% for root length to 19.83% for seedling survival rate, indicating high experimental precision and reliability of the data. The critical difference (C.D.) values further confirmed the presence of substantial genetic variability among treatments for the measured parameters.

Effect of seed germination and seedling traits in greengram under EMS induced mutagenesis

Seed Germination (%)

The seed germination percentage showed a decreasing trend with increasing EMS concentration. The highest germination (93.33%) was observed at 0.05% and 0.1% EMS, which was equal to the untreated control (86.67%), indicating that lower concentrations had little or no adverse effect on germination. A gradual decline was recorded beyond 0.2% EMS, where germination dropped to 86.67%, followed by 73.33% at 0.3%, 66.67% at 0.4%, 60.00% at 0.5%, and 46.67% at 0.6% EMS (Table 2). The reduction in germination at higher concentrations suggests that EMS exerts a dose-dependent inhibitory effect on seed viability and embryo metabolism.

Shoot Length (cm)

Shoot length exhibited slight stimulation at lower EMS concentrations and a marked reduction at higher doses. The maximum shoot length (14.27 cm) was recorded at 0.1% EMS, which was higher than the control (12.86 cm), indicating a mild stimulatory effect of low EMS doses on seedling elongation. Beyond this level, shoot length declined steadily to 12.06 cm (0.2%), 7.63 cm (0.3%), 7.17 cm (0.4%), 6.97 cm (0.5%), and 5.98 cm (0.6%)(Table 2).

The continuous decline at higher doses reflects growth retardation due to mutagen-induced physiological and cytological damage.

Root Length (cm)

Root length followed a similar pattern as shoot length. The longest roots (5.34 cm) were observed at 0.1% EMS, followed by 4.05 cm at 0.05%, both higher than the control (3.98 cm). However, a progressive reduction was recorded at higher EMS concentrations -3.78 cm (0.2%), 3.00 cm (0.3%), 2.45 cm (0.4%), 2.46 cm (0.5%), and 2.23 cm (0.6%)(Table 2). The reduction in root length at higher doses indicates inhibition of cell division and elongation in the root apical meristem due to toxic and mutagenic effects of EMS.

Table 2. EMS mutagenic effect on seed germination% and seedling traits in greengram

EMS Conc.	Seed germination%	Shoot Length (cm)	Root length cm	Seedling Vigor Index	Seedling Survival rate %
0.05%	93.33	13.33	4.05	1244.13	93.33
0.1%	93.33	14.27	5.34	1331.87	93.33
0.2%	86.67	12.06	3.78	1045.20	85.00
0.3%	73.33	7.63	3.00	559.53	83.33
0.4%	66.67	7.17	2.45	478.00	72.22
0.5%	60.00	6.97	2.46	418.20	55.56
0.6%	46.67	5.98	2.23	279.07	44.44
Untreated	86.67	12.86	3.98	1114.53	93.33
Min	***46.67***	***5.98***	***2.23***	***279.07***	***44.44***
Max	***93.33***	***14.27***	***5.34***	***1331.87***	***93.33***
SD	***17.067***	***3.395***	***1.068***	***416.999***	***18.687***

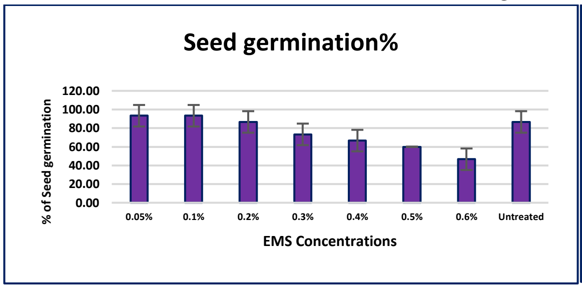
Seedling Vigor Index (SVI)

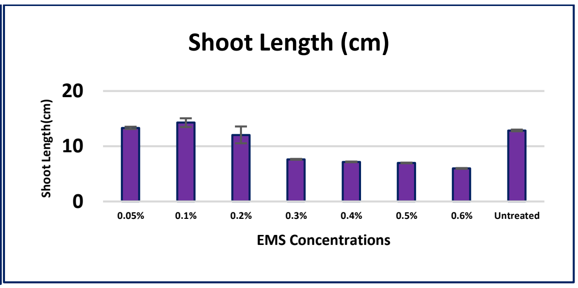
The Seedling Vigor Index (SVI) increased slightly at lower concentrations and decreased drastically at higher doses. The highest vigor index (1331.87) was obtained at 0.1% EMS, followed by 1244.13 at 0.05%, and 1114.53 in the control(Table 2). This suggests that low EMS concentrations may enhance early seedling growth through a hormetic (stimulatory) effect. However, higher EMS levels caused a pronounced reduction in vigor: 1045.20 (0.2%), 559.53 (0.3%), 478.00 (0.4%), 418.20 (0.5%), and 279.07 (0.6%), showing a dose-dependent inhibition of growth vigor

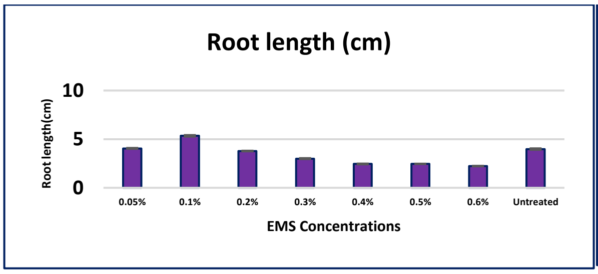
Seedling Survival Rate (%)

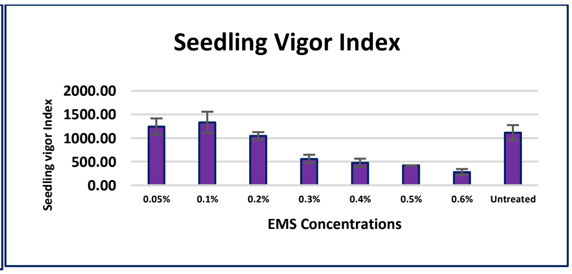
Seedling survival percentage remained high at low EMS doses and declined sharply with increasing concentration. The highest survival (93.33%) was observed in 0.05% and 0.1% EMS, equal to the untreated control. A gradual decline occurred beyond 0.2% EMS with 85.00% (0.2%), 83.33% (0.3%), 72.22% (0.4%), 55.56% (0.5%), and 44.44% (0.6%) survival(Table 2). The decrease in survival at higher EMS levels indicates that mutagenic stress and cellular damage increased proportionally with EMS concentration, reducing the ability of seedlings to establish and survive.

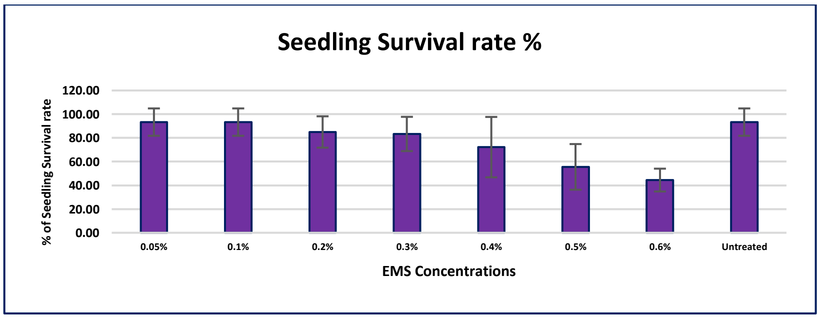
The study revealed that the response of greengram seedlings to different concentrations of Ethyl Methane Sulphonate (EMS) varied significantly across all seedling traits, including germination percentage, shoot and root length, seedling vigor index, and survival rate. The observed variation indicates that EMS exerted both stimulatory and inhibitory effects depending on the dose applied.At lower EMS concentrations (0.05% and 0.1%), seed germination, shoot length, root length, and seedling vigor index were either similar to or slightly higher than the untreated control. This suggests that mild doses of EMS may have stimulated cellular metabolism and enzymatic activity, leading to better germination and seedling growth. Similar low-dose stimulation has been reported in greengram by Sen et al, 2022; Bhattu et al., 2023 in blackgram; Yugandhar et al., 2023 in groundnut. However, as the EMS concentration increased beyond 0.2%, there was a progressive and significant decline in all the measured parameters. The decline in germination percentage and seedling survival rate at higher concentrations (0.3-0.6%) indicates that EMS caused deleterious genetic and physiological damage to the embryo, impairing its normal development. The reduction may be attributed to alterations in nucleic acids, enzyme inactivation, and disruption of metabolic pathways involved in germination and seedling growth. These results align with findings by several researchers who reported dose-dependent inhibition of growth and survival in EMS-treated seeds of crops byKhan and Goyal, 2009, Sen et al, 2022 in green gram; Bhattu et al., 2023 in blackgram; Yugandhar et al., 2023 in groundnut. The reduction in shoot and root length at higher EMS levels indicates that cell division and elongation in meristematic tissues were adversely affected. EMS is an alkylating mutagen that ethylates guanine bases in DNA, leading to point mutations and disturbances in gene expression. Such genetic alterations can inhibit cell proliferation, resulting in stunted shoot and root development. The root growth was more sensitive to EMS than shoot growth, possibly because root apical meristems are directly exposed to the mutagenic solution and are more susceptible to cytotoxic effects.The seedling vigor index (SVI), which integrates both germination and seedling growth, showed a clear dose-dependent reduction. The highest vigor observed at 0.1% EMS suggests that low concentrations may induce mild stress, activating adaptive physiological mechanisms that temporarily enhance growth. However, at higher concentrations, oxidative stress and metabolic imbalance caused a severe reduction in vigor, reflecting mutagenic lethality and growth retardation.The seedling survival rate followed a similar pattern, decreasing sharply at higher EMS doses. The reduced survival percentage is indicative of chromosomal abnormalities, gene mutations, and physiological damage, which limit the ability of seedlings to recover and establish normal growth. The pattern of decline across parameters suggests that EMS toxicity in greengram is concentration-dependent, with 0.1% EMS being the optimum mutagenic dose for inducing variability with minimal lethality.The results demonstrate that EMS, at low concentrations, can be effectively used to induce genetic variation without severely compromising germination and growth. However, higher EMS concentrations lead to lethal and sublethal effects, which manifest as poor seedling establishment and reduced vigor. These findings are consistent with the general mutagenic response observed in pulse crops, where moderate EMS doses are recommended to achieve maximum mutation frequency with minimum biological damage (Khan and Goyal, 2009, Sen et al, 2022 in greengram; Bhattu et al., 2023 in blackgram; Yugandhar et al., 2023 in groundnut).











III. CONCLUSION

The results can concluded that lower EMS concentrations (0.05-0.1%) showed no adverse effects and even stimulated growth and vigor slightly. Moderate and high EMS concentrations (≥0.2%) caused progressive reductions in all traits. The optimum EMS concentration for inducing variability with minimal injury was found to be 0.1%. All traits exhibited a dose-dependent inhibitory response at higher EMS levels, confirming the toxic nature of EMS at elevated concentrations.

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A comprehensive Review on Formulation, Characterization, Composition, Stability & Preparation, of Nanoemulsions

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Abstract— *The use of Essential Oils (Eos) alone is limited due to their disadvantages such as high volatility, low stability, bioavailability and solubility. Therefore, Essential Oils are generally use in the form of nanoemulsions. The food and pharmaceutical sectors have shown a great deal of interest in essential oil-based nanoemulsions (EO-NEs) because of their improved stability, bioavailability, and functional properties. Nano-based emulsions havereceived considerable attention recently due to their physico-chemical properties and kinetic stability , attractive appearance. Furthermore, their rheological properties make them superior over counter parts. The ability of nanoemulsion to improve the solubility, bioavailability and stability of weakly water-soluble drugs has emerged their roles as promising drug delivery systems, drug administration and vaccine formulation, cosmetics, and food, it also has numerous applications in the field of agriculture. Nevertheless, their benefits, some concerns may represent obstacles that hinder their applications such as formulation complexity, stability issues and industrial production scale-up. To get beyond these hurdles and completely realize the potential of nanoemulsion in commercial and therapeutic applications, more research and innovation are need. This review intends to offer an overview of the formulation, Characterization, Composition, Stability & Preparation, of nanoemul sions specifically, recent literature has been examined in order to define the most common practices adopted (materials and fabrication methods), highlighting their suitability and effectiveness. Finally, relevant to some points such as advantages disadvantages, and applications of nanoemulsions.*

Keywords*— *Characterization, Essential Oils, Formulation, Nanoemulsions, Preparation.

I. INTRODUCTION

Essential oils (EOs) are secondary metabolites from aromatic plants. Moreover, they are plant-derived oily bioactive compounds from various parts like roots, leaves, flowers, and seeds. Through methods such as steam distillation, cold pressing, steam distillation, microwave or ultrasound assisted extraction etc [1, 2]. Essential oils are a complex mixture of various bioactive chemical molecules, they are typically use in small quantities due to their potent aroma and flavor, they are recognised as safe by both the US Food and Drug Administration (FDA) , applications and can used as alternatives to chemical preservatives [3 - 6]. Due to these diverse, complex bio-structures, essential oils have been widely used in the traditional medicine as essential oil posse various biological activities like antimicrobial, antiviral, fungicidal, insecticidal and herbicidal, antioxidant, anti-inflammatory, anti-allergic, anticancer agents, expectorant, digestive, diuretic agents [7, 8]. The biggest challenges of modern botany is to move towards the replacement of synthetic compounds with natural ones, including EOs, in order to exploit their promote sustainable development based on a circular economy [8]. Interest in these kinds of plant based secondary metabolites is increasing day by day [9, 10]. Essential oils have poor physico-chemical properties, such as water insolubility [11]. However, these problems can be preventing through the encapsulation of EO within appropriate delivery systems, thereby amplifying their biological efficacy, [12].Therefore; nanoemulsification technology offers a good alternative for encapsulating these bioactive compounds, making them hydrophilic [13].

Recently, medical studies showed a possible anticancer activity of some EOs, attributable to an antimutagenic (i.e., *Salvia officinalis* L., *Origanum onites* L. and *compactum*, *Lavandula angustifolia* EOs [14, 15] and prooxidant activity (i.e., *Origanum compactum*, *Artemisia herba-alba* and *Cinnamomum camphora*, *Glandora rosmarinifolia* EOs [16, 17]. This latter is a fundamental property to reduce local tumor volume and cell proliferation [18]. The studies was confirmed that the main components of Cinnamon essential oils (CEO), such as limonene and Cinnamaldehyde, have strong antimicrobial effects on foodborne pathogens like Escherichia coli and Listeria monocytogenes [19]. In addition, encapsulating extracts from graviola leaves [20], garlic [21], pep-permint [22], basil oil [23], and CEO in nanocapsules enhances their antimicrobial andantioxidant properties, thereby optimizing growth, gastrointestinal health [21]. The interest in nanoemulsions has experienced a continuous increase in the last years, emulsification is the process of dispersing two or more immiscible liquids together to form a semi stable mixture ([24- 26]. Nanoemulsions are three main components used in the preparation of nanoemulsions are oil, surfactant and cosurfactants have unique physicochemical properties [27-32]. Emulsions (liquid droplets and/or liquid crystals dispersed in a liquid) are prepared using nanotechnology (1-100 nm) by reducing the surface tension between the dispersed and dispersed phases. This is usually achieved through vacuum and electrostatic repulsion between the emulsions, is preferred, the stability of emulsions, which ranges from a few hours to several years, is influenced by important characteristics related to the preparation procedures and the ingredients used. Mollet and Groppenmann emphasize that emulsification requires both chemical and physical energy [33- 38]. Nanoemulsion is a nonequilibrium mechanism that is create with the aid of an external or internal energy source. This is accomplish by a variety of methods that are grade as either high-energy or low-energy by using mechanical devices [39]. Emulsions, which are prepared using nanotechnology, characterized by; exhibit excellent skin penetration and long-lasting effects. In contemporary times, nano-drug delivery systems have emerged as a highly effective approach for delivering drugs within the human body [40-44]. Nanoencapsulation based nanoemulsions, play a pioneering role in encapsulating herbal, Tween-20 and 80 are nonionic, biocompatible, and non-toxic surfactants and widely implicated in medicine, cosmetic, food industries products as used as emulsion surfactants [45-50]. The nanoencapsulation approach could improve the essential oils' physico-chemical properties and stability, by enabling their water dispersability, and by protect them from the interaction with the environment [51].

This work will endow with new information about nanoemulsions based on essential oils in different areas such as food, cosmetic, and pharmaceutical drug delivery systems. In addition, offer a technical overview on the formulation, preparation and stability parameters of Molecular extracts and Nano-extracts when used as vehicle and delivery systems for essential oils, based on the most relevant works reported in the literature in the last years. Moreover, it aims to provide a formulation guide for researchers that need to encapsulate essential oils in such Nano systems.

II. NANOEMULSIONS FORMULATION

An understanding of the physics of nanoemulsion formation is critical for the control of nanoemulsion droplet size. Nanoemulsions are typically prepared in a two-step process where a macroemulsion is first prepared, and is then converted to a nanoemulsion in a second step [52]**.** There are a number of techniques for preparing nanoemulsions, such as high-pressure homogenization, microfludization, phase inversion, spontaneous emulsification, solvent evaporation and hydrogel formation. Multiple emulsions are usually prepared using the double emulsion-solvent evaporation technique. [53]**.**

Theories of Nanoemulsions Formulation

1. **Solubilization Theories**

it is believed that the nano emulsion is getting closer to thermodynamically stable monophasic solutions of spherical micelles that are swelled in water (w/o) or oil (o/w) [54].

2. Interfacial theory

It is also called as mixed film,the surfactant and co-surfactant form a complex layer at the oil-water interface, which is what cause the spontaneous creation of nanoemulsion droplets. According to the general provisions of the theory, an increase in the degree of dispersion of micro droplets can be achieved by lowering the interfacial tension at the water–oil interface to reaching extremely low values (from almost zero to negative). As Shulman's work [55]. This is represent by the equation below:

yi=y0/w- πi (equation 1)

Where, y0/w: Oil-water interfacial tension, πi:Spreading pressure, yi= interfacial tension [56]**.**

3. Thermodynamic theory

When interfacial tension between two immiscible phases reduces to zero, causes spontaneous formation of micro emulsions and formed negative free energy helps to make emulsion thermodynamically stable [57]. T. P. Hoar and J. H. the term microemulsion when they used this term to describe multiphase system . Discovery of microemulsions confirms well before use in the form liquid waxes., there are four types of micro emulsion phases exists in equilibrium, these phases are referred as Winsor phases [58, 59].

III. PHYSICOCHEMICAL CHARACTERIZATION ON NANOEMULSIONS

3.1. Droplet size & distribution

The normal range of droplet sizes for nanoemulsion is 20-500 nanometers. area-to-volume ratio produced by the small droplet size improves the interaction between the nanoemulsion and biological membranes, enhancing the absorption and bioavailability of the materials that are entrapped [60, 61]. As the droplet size is significantly smaller than the wavelength of visible light, nanoemulsions are often transparent in appearance [62]. Nano-emulsions size distribution is the most important parameters of nano-emulsions since it is relate to applicative properties [63, 64]. Methods used for size characterization include photon correlation spectroscopy (PCS) (i.e., dynamic light scattering, DLS), fluorescence correlation spectroscopy (FCS), electron microscop [65, 66].

3.2. Zeta potential analysis

The liquid layer surrounding the particle exists as two parts; an inner region (Stern layer) where the ions are strongly bound and an outer (diffuse) region where they are less firmly associated. Within the diffuse layer, the ions and particles form a stable entity inside a notional boundary. When a particle moves (e.g. due to gravity), ions within the boundary move it. Those ions beyond the boundary stay with the bulk dispersant. The potential at this boundary is the zeta potential [67, 68]**.** Sakhalin et al. designed the first zeta potential changing nanoemulsion exhibiting a zeta potential change from just -1 mV to +1 mV [69]. Up to date, all zeta potential changing nanoemulsions contain a cationic surfactant being responsible for a positive zeta potential [70]. Concept of zeta potential is rooted in the examination of electro kinetic phenomena, which describe the relative motion between a charged surface and a liquid under the effect of an electric field. The most frequently encountered electro kinetic phenomena used to measure zeta potential are Electrophoresis, Electro osmosis [71, 72].

3.3. Viscosity

The viscosity of freshly prepared nanoemulsion samples usually measured using a Brookfield DV-ETM viscometer. [73]. The proportions of water, oil, and surfactant in a nanoemulsion determine its viscosity, Lowering the content of cosurfactants and surfactants raises viscosity by raising the interfacial tension between the water and oil, whereas raising the water content lowers viscosity [74, 75].

3.4. Encapsulation efficiency (EE)

Encapsulation of essential oils in nanoemulsions systems represents a viable and efficient approach to increase the physical stability of bioactive compounds. Thus protecting them from loss and undesirable changes [76]. Indeed, the use of this technology gains special relevance when it comes to the formulation of biopharmaceuticals [77]. Encapsulation Efficiency (EE) was regarded as a bulk property and was measured as the average of all DDS particles in a solution. Recent technical advances however, allowed the monitoring of single particles [78, 79], to unique information on heterogeneous properties that were lost due to averaging [80]. Encapsulation Efficiency is calculated by following equation:

$$(EE)\,\% = \frac{\text{Total oil} - \text{Free oil}}{\text{Total oil}} \times 100$$ **(equation 2)** [81 - 83]

The encapsulation efficiency of the micro particle or microcapsule or microsphere will be affect by different parameters. Figure 1 illustrates the factors influencing encapsulation efficiency [84].

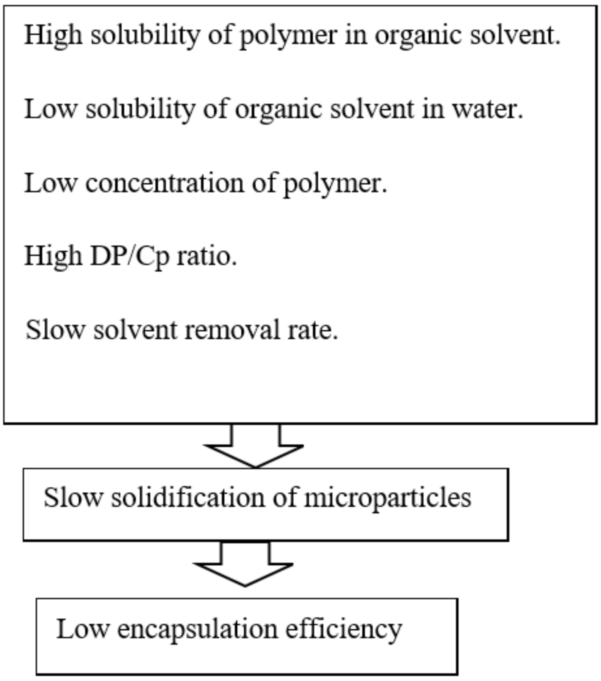

Fig.1: factors influencing encapsulation efficiency [85].

3.5. Surface tension

Surface tension usually measured using a thermostatically controlled processor tensiometer K10 PST at 22 °C [86].

3.6. Rheological measurements

The rheological properties of Nano-emulsions can be turn from flowing fluid to a solely relaxing fluid or to a gel-like system by controlling the dispersed phase volume fraction and droplet size, or by adding additives in the bulk [87].the study of interfacial properties, surface tension and dilatational rheology is getting more and more attention in recent years [88]. Rheological measurements usually done perform at 25±0.1°C using a Bohlen remoter equipped with a cone/plate apparatus 40 mm per 4°. For each sample, continuous variation of shear rate γ will applied and the resulting shear stress σ will measured. Viscosity of dispersions with Newtonian flow properties calculated according to the relation: $\eta=\sigma/\gamma$ (equation 3) [89].

IV. COMPOSITION OF NANO EMULSIONS

4.1. Emulsifier

An emulsifier has the ability that mixes two immiscible liquids (oil and water) to form a homogeneous dispersion. It plays a significant role in the food industry and it could prevent phase separation. [90]. Food colloids emulsions and foams have their origins in nature, Milk, for example, has a naturally occurring membrane, which allows solid fat to be disperse into an aqueous phase [91].

Table 1: Properties of emulsions [92, 93].

Emulsion	Droplet Size	Thermodynamic Stability	Appearance
Nanoemulsion	5-200 nm	Unstable	Transparent
Microemulsion	5-100 nm	Stable	Transparent
Macroemulsion	0.1-100 µm	Unstable	Turbid

4.2. Oil phase

The oil phase could consist in a carrier oil in which the lipophilic bioactive compound dissolved [97]. Oil-in-water miniemulsions are prepared at slow agitation by an emulsification process that involves the use of mixed emulsifier solutions of an ionic surfactant [98]. Penetrating the tail group region of the surfactant monolayer and causing it to swell, the oil components also affect curvature [99]. Because short chain oils, penetrate the lipophilic group more [100]. Nano-emulsions are thermodynamically unfavorable systems [101], the chemical stability is also important for quality control of the drug-loaded Nano-emulsions [102, 103]. Some plant oils (corn, olive, sunflower, sesame, oils) defined as “ripening inhibitors” is needed [104-107]. Plant oils less water-soluble, they are able on positively influence their partitioning between the lipid droplets and the aqueous phase, for these reasons, several works in the literature reported the mixing of essential Oils, acting as active ingredient, and ripening inhibitor oils, in order to guarantee the long-term stability of the system [108, 109].

4.3. Surfactant

A surfactant molecule consists of two parts. One part is hydrophobic and the other one is hydrophilic. These molecules are highly active in the interfaces between air and water or oil and water. There are four main classifications of surfactants: anionic, nonionic, cationic and amphoteric surfactants, therefore, proper selection of surfactants becomes a crucial criterion. [110, 111]. Surfactants are essential for stabilizing nanoemulsions [112]. These amphiphilic molecules form a protective layer around droplets, offering steric, electrostatic, or dual electro-steric stabilization [113]. The selection of surfactants depends on the desired droplet size, stability, and application. Cosurfactants are often added to strengthen the interfacial and further stabilize the emulsion. Examples include polyethylene glycol [114, 115].

Table 2: Types of surfactant [116 - 119]

Sr. No	**Types of surfactant**	**Examples**
1	**Non-ionic**	Sorbitan monooleate (Span 80), Tween 80
2	**Cationic**	Ecithin , soybean egg,. Quaternary ammonium alkyl salts
3	**Anionic**	Sodium bis-2-ethylhexylsulphosuccinate (AOT)
4	**Ampholytic**	Phospholipids (Lecithin, Ndodycylalanine**)**

4.4. Co-surfactant

Drugs that are not water-soluble usually made into emulsion preparations. Emulsion preparations have poor stability; surfactants are ingredients that affect nanoemulsions to reduce surface tension [120]. Surfactants have unique molecular characteristics; a short to medium hydrophobic chain, weak amphiphilic nature, and terminal small hydrophilic group (such as hydroxyl group characteristic of low molecular weight alcohols and diols). These properties increase the tendency of cosurfactants to interact with surfactant monolayers at interfaces, perturbing the packing and long-range order of surfactant molecules and promoting better interface fluidity and curvature in favor of NE formation [121]. Furthermore, the balanced amphiphile nature of these molecules promotes their selective partitioning between phases, changing their composition and thereby their relative hydro/lipophilicity of the immiscible phases to improve better miscibility [122].

Table 3: List of co-surfactant used in nanoemulsions [123]

Sr. NO	Co-surfactant
1	TranscutolP
2	Glycerin,Ethylene glycol
3	Propylene glycol
4	Ethanol
5	Propanol

V. STABILITY

5.1. Centrifugal stability

The stability of nanoemulsions under centrifugation reflects the emulsion resistance and the integrity of the interfacial film [123,124].use varying speeds (3000, 5000, and 8000 r/min) for 30 min, the absorbance of the non-layered emulsion is then measured at 210 nm before and after centrifugation, using distilled water as a reference sample. The permeability calculated using the following equation:

Transmittance formula: T (%) = A1/A2 × 100 **(equation 4)**

Where: T: transmittance; A1: absorbance of nanoemulsion before centrifugation; A2: absorbance of nanoemulsion after centrifugation [99].

5.2. Thermal stability

Increased temperatures can cause droplets to absorb energy in the Nano-emulsion, resulting in the emulsification, coalescence and flocculation of the Nano-emulsion [125]. Over time, they evolve into two distinct liquid phases, an irreversible process driven by the lower free energy level of the phase-separated state compared to the emulsion state [126]. The kinetics of Nano emulsion breakdown follow a first-order rate law, where the rate is exponentially proportional to $\exp(-\Delta E/kBT)$, with ΔE denoting the energy barrier, representing the Boltzmann constant, and T indicating the temperature [127]. The irreversible breakdown poses significant constraints on the utility of Nano emulsions, especially in scenarios where exposure to high temperatures during production, storage, or application is inevitable, such as in food processing, formulations, and pharmaceutical [128].

5.3. PH stability

The pH value of the Nano emulsion systems adjust by adding Hydrochloric acid or Potassium hydroxide to the system, which monitor by using a Sartorius basic pH [129].To pH testing conduct use the methodology described by Shoviantari et al. [130].Before evaluating the preparation's pH, the pH meter will be calibrate using buffer solutions (pH 4.00, 7.00, and 10.00). To guarantee its correct functioning. [131].

5.4. Storage stability

There are few studies have investigated the storage stability of Nano emulsion droplets; Environmental conditions that effect on the stability of emulsions include temperature, pH, and ionic strength [132- 134].The emulsion stored at higher temperatures increases the thermal energy of the droplets and therefore increases the frequency of droplet collisions. It also reduces interface viscosity, which results in a faster film-drainage rate and faster droplet coalescence [135]. Nano-emulsions have a long kinetic stability that can be maintaining for months because of their small size and low dispersion index. When the Nano-emulsion droplet size is less than 200 nm, the Nano-emulsion is highly resistant to gravitational separation, which is ideal for the development of products with a long shelf life [136]. The shelf of Nano emulsions is tested by storing a sample of fresh emulsion (5 ml) in a sealed container at 25°C for 2, 4, 6, 12, and 24 days respectively. The droplet size, dispersion index (PDI), and zeta potential are then measured at each storage period [125].

VI. NANO EMULSIONS PREPARATION

Nano emulsions can be prepared by using high and low energy methods. In high-energy methods, mechanical devices deliver required large disruptive forces. On the other hand, in low energy methods, there is no need for an external force [137]. Production of Nano emulsions achieved by using the intrinsic physiological properties of the system. [138].The most extensively used methods for the preparation of Nano emulsions: are Spontaneous Emulsification Method (SE), Phase inversion Temperature method (PIT), Emulsion phase inversion (EPI) method/ catastrophic phase, Emulsion inversion point (EIP) method, High-pressure homogenization (HPH) method, Micro fluidizers, High-Intensity Ultrasound (HIU), and Rotor stator mixer [139].

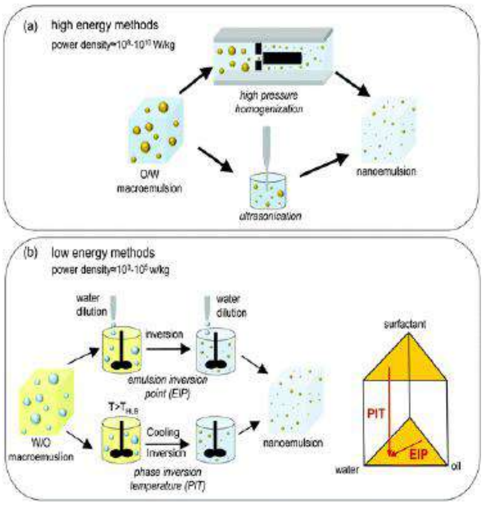

Fig.2: Nano emulsions Preparation

6.1. Low-energy methods

Low-energy approaches rely on the spontaneous for-mation of tiny oil droplets within oil-water-emulsifier mixtures when either their composition or the environment conditions are altered [140]. A number of different Nano emulsion preparation methods based on this principle, including: [141].

6.1.1. Spontaneous emulsification method (SE)

The spontaneous formation of an O/W Nano emulsion facilitated by specific temperatures relies on the chemical compounds present in both phases, as well as the utilized emulsifier [142]. Solvents can facilitate this spontaneous process [143]. It benefits from the chemical energy replacement based upon dilution process with the continuous phase, which occurs usually at constant temperature [144]. This method can produce Nano emulsions at room temperatures and no special devices are required. It subjected to interfacial tension, viscosity of interfacial and bulk, phase transition region, surfactant structure, and surfactant concentration. [145].

6.1.2. Phase inversion temperature method (PIT)

In the PIT method, Nano emulsions prepared by the formation of micro emulsions at its PIT followed by immediate cooling to room temperature, which can be divided into 3 main steps:

1. Non-ionic surfactant, oil and water stirred at room temperature to form a coarse emulsion [146].

2. The mixture gradually heated up to around PIT [147].

3. The solution rapidly cooled to the room temperature with continuous stirring, resulting in the formation of o/w Nano emulsions, mixture is rapid cooled either by immersing into an ice bath or by diluting with cold water [148]. Inversion Temperature method (PIT) has the advantage over SE method in that its composition is without organic solvent which is an integral component of the SE method. The PIT method also has superiority over the PIC method in that the nanoemulsion droplets have lower diameter and polydispersity index (PDI). The emulsification efficiency of PIT method has also been found higher (1) than that of PIC method (0.35)40 [149, 150].

6.1.3. Emulsion phase inversion (EPI) method/ catastrophic phase

Nano emulsions can be fabricate using either low-energy emulsification (e.g., transitional phase inversion) [151,152]. Although low energy emulsification methods use higher amounts of surfactants, it requires only a simple stirring to produce an emulsion with desirable characteristics [153,154]. Which makes them more energy efficient opposed to high-energy methods, which require the use of mechanical devices [154]. The Emulsion Phase Inversion (EPI) method, is a low-energy technique for creating fine emulsions, by agitated water-in-oil (O/W), emulsion inverts into an oil-in-water (W/O) emulsion and vice versa. There are two types of phase inversion; transitional phase inversion and catastrophic phase inversion (CPI) [155]. Emulsification via phase inversion is widely used in fabrication of cosmetic products, pharmaceutical products (e.g., vesicles for drug delivery), foodstuff and detergents. Emulsification process strongly affected by preparation method; very different droplet size distribution could be achieved, which is strictly linked to the product stability [156]. The phase inversion of a W/O emulsion can be achieved not only through changes in thermodynamic state variables but also by the imposition of ultra-high deformation rates under constant thermodynamic conditions. Phase inversion carried out using a model static mixer, which is essentially a series of short capillaries with flow dividers. His degree of phase inversion is dependent on the rate of deformation and number of mixer units. The properties of the emulsions produce by FIPI-emulsification are evaluated through particle size and viscosity measurements and optical and electron microscopy studies [157]. **6.1.4. Emulsion inversion point (EIP) method**

In the emulsion inversion point (EIP) methods the change from one type of an emulsion to another (e.g., W/O to O/W or vice versa) is through a catastrophic phase inversion (CPI), rather than a transitional phase inversion (TPI) as with the PIC or PIT methods [158]. In this case, a W/O emulsion with a high oil-to-water ratio is formed using a particular surfactant, and then increasing amounts of water are added to the system with continuous stirring. Above a critical water content, the water droplet concentration is so high that they are packed very tightly together, and the emulsion reaches a phase inversion point where it changes from a W/O to an O/W system. The size of the droplets formed depends on the process variables, such as the stirring speed and the rate of water addition [159]. Recently, it has been shown that the emulsion inversion point (CPI) method can be used to produce Nano emulsions (r< 100 nm) from food-grade ingredients [160, 161].

6.2. High energy methods

6.2.1. High-pressure homogenization (HPH) method

High pressure homogenization (HPH) was first introduced in the early 20th century by Auguste Gaulin, the basic operational principle of HPH remains unchanged since and it involves using a high-pressure pump to force the fluid through a small orifice. [162]. In the emulsion fabrication, a mixture of essential oil and Tween 80 (as surfactant) is disperse in distilled water, using a magnetic stirrer at 1500 rpm for 15 min, to form a primary emulsion. Subsequently, the primary emulsions subjected to a high-pressure homogenization [163].

Table 4: Preparation of nanoemulsions using Spontaneous Emulsification Method (SE) with different oils

Method	Bioactive Compound Encapsulated	Optimal Processing Conditions	Droplet Diameter (nm)	Ref
Spontaneous Emulsification Method (SE)	Peppermint oil	(1) titration of organic phase into aqueous phase, (2) constant stirring, 600 rpm, (3) room temperature	50	[164, 165]
	Eugenol oil	(1) deprotonated Eugenol in hot alkaline added to surfactant mixtures, (2) the mixtures acidic to pH 7.0, stirred, 600 rpm	109–139	[166]
	Black Cumin oil	Mix cumin essential oil with Tween 80 and distilled water using a magnetic blender for five minutes.	122.7	[167]
	mustard oil	1-Blends of Tween 20 and SDBS in a range of 1:1–1:6 ratios. 2-Mustard oil (5% w/w) add drop wise into different blends of emulsifier with slow mixing by magnetic stirrer at 50–60°C for final preparation of oily phase. 3- Aqueous phase form by adding two co-surfactants, in de-ionized water.	23	[168]
	pine oil	The method: Mix pine oil +Tween 80 + ethanol in + water with total cumulative value of all components not more than 100% v/v	633	[169]

Table 5: Preparation of nanoemulsions using Phase inversion &Emulsion inversion point Methods with different oils

Phase inversion Temperature method (PIT)	Curcuminoids	1. Non-ionic surfactant, oil and water are stirred at room temperature to form a coarse emulsion 2. The mixture is then gradually heated up to around or above the PIT. 3. The solution is rapidly cooled to the room temperature with continuous stirring..	20-100	[170]
	Lemon oil		100	[171]
	coconut oil		20-100	[146]
	ginger oil		100	[147] [148]
	Harmal oil	combining the essential oil with surfactants (like Tween 80/Span 20) and water, then mixing and homogenizing to create stable, nanometer-sized droplets	There is no study	
Emulsion phase inversion (EPI) method/ catastrophic phase	coconut oil	80 or Tween 20 & oil are prepare and add to it different amounts of water and the mixture was mixed using a vortex, for two minutes.	20-100	[172]
	Oregano Essential Oil		170-180	[173]
	Fenugreek oil		< 100	[174
	canola oil		156.13 ± 2.3	[175]

	orange oil		146-200	[176]
	sesame oil		100	[177]
	Mexican Tea essential oil		Suggested:	
Emulsion inversion point (EIP) method	Castor oil	slowly adding water to an oil-surfactant(tween 80) mix, which suddenly transforms the system into tiny droplets at low interfacial tension.	35 ± 45	[178]
	coconut oil (VCO)		<300	[179]
	paraffin wax		<200	[180]

Table 6: Preparation of nanoemulsions using High-pressure homogenization (HPH) method with different oils

Method	Essential oil	Surfactant	Aqueous Phase	Size (nm)	Ref
High-pressure homogenization (HPH) method	fish oil	Tween80	sodium Caseinate	369.4 ± 3.8	[181]
	clove essential oil	Tween 80	Distilled water	90	[163, 182]
	lemon essential oil	Tween 80	Distilled water	100-140	[163]
	Saccocalyx satureioides Coss. essential oil	Tween 20	Distilled water	106,000	[183]
	Cinnamon essential oil	Tween 80	Lauric arginate	100	[184]
	cardamom oil	Tween 80	grape seed oil		[185]
	bergamot essential oil	xanthan gum	Distilled water	63.6 - 85.3	[186]
	groundnut oil	Tween 80	Distilled water	20-200	[187]
	borage oil	Tween® 80	Distilled water	334.4 ± 5.2	[188]
	Cellulose derivatives	Tween 20, 60, or 80	Distilled water	100-126	[189]

Table 7: Preparation of nanoemulsions using microfluidizers and high-intensity ultrasonic (HIU) devices with different oils

Method	Essential oil	Surfactant	Aqueous Phase	Size (nm)	Ref
Microfluidizers	Corn oil	quillaja saponin and soy lecithin	Whey protein isolate (WPI)	20-200	[190]
	linseed oil	lecithin	Distilled water	70.8	[191]
	Mineral oil	lecithin	Distilled water	<200	[192]
	Chia Oil	NaCas	Distilled water	< 200	[193]
	orange oil	gum Arabic and modified starch	Distilled water	77	[194]
High-Intensity Ultrasound (HIU)	olive oil	Tween 80, Span 60, or sucrose esters	Distilled water	< 200	[195]
	Castor Oil	Tween 80	deionized water	174.6	[196]
	Cady oil	Tween 80	deionized water	< 200	[196]
	Neem oil	Tween 20	Distilled water	< 100	[197, 198]
	Almond Oil	Tween 20	Distilled water	< 100	[199]
	juniper berry essential oil	Tween 20	deionized water	182-250	[200]

	Curcumin	soybean lecithin	glycerol in the aqueous phase	108	[201]
	Thyme Essential Oil	Tween 80	deionized water	54.6	[202]
	ginger oil	Tween 80	buffer or distilled water, ethanol	< 100	[203, 204]
	grapeseed oil	Tween 80	Distilled water	144.2 - 162.6	[205]
	Moringa Oil	whey proteins	Distilled water		[206]
	Garlic essential oil	Tween 80	Distilled water	215-820	[207]
	Aloe vera oil	Span® 85	Distilled water	< 200	[208]
	safflower oil	polysorbate 80	Distilled water	88.14 ± 1.52	[209]
	Basil oil	Saponins extracted from Quillaja lancifolia	Distilled water	174.1	[188]
	celery seed oil	Tween 80	Distilled water	23.4 ± 1.80	[210]
	lavender oil	Tween-80, Span-80, ethanol	Distilled water	-----	[211]
	Qassum oil	Tween 80/Span 80	Distilled water	Suggested: There is no study	

Table 8: Preparation of nanoemulsions using Phase inversion composition (PIC) &Spontaneous emulsification methods (SE) with different oils

Method	Essential oil	Surfactant	Aqueous Phase	Size (nm)	Ref
Phase inversion composition (PIC)	Neem oil	Tween 80	Distilled water	194	198]
	Ginger oil	Tween 80	Distilled water	20–75	[212]
	coconut oil	Tween 80/Span 80 or lecithin	Distilled water	48.63	[179]
	Origanum Essential Oil	linseed mucilage	Distilled water	170-180	[173]
Spontaneous emulsification method (SE)	Lime Essential oil	Tween 80	Distilled water	20–60	[163]
	Cinnamon oil	Tween 80	Distilled water	100	[184]
	Peppermint Essential oil	Tween 20, 40, 60	Distilled water	70–170	[164]
	Clove oil				[182]
Phase Inversion Temperature (PIT)	oregano essential oil	Cremophor RH 40, Span 80	Millipore water	30–60	[213]
dynamic light scattering	Elongate oil	deionized water	non-heated water	115	[214]

6.2.2. Micro fluidizers

Two solutions (aqueous phase and oily phase) are united together and processed in an in-line homogenizer to create a coarse emulsion, which allowed into a Microfluidizer where it is further developed to obtain a steady Nano emulsion. [215]. It is most widely employed in the pharmaceutical industry [216]. In nanoparticle production, this process facilitates the size reduction and uniform dispersion of materials. For example, in the production of liposomes and lipid nanoparticles (LNPs), [217, 218].

6.2.3. High-intensity ultrasound (HIU)

Industrial scale emulsion formation typically takes place in highpressure homogenizers (HPHs) [219]. HPHs used widely in many branches of chemical engineering, ranging from traditional dairy applications to Nano emulsification in pharmaceutical production and more [220]. Advantages of these devices high-energy efficiency, and Good emulsion stability - HIU devices are easy to operate and clean [221]. Ultrasound devices can produce acoustic cavitation, releasing of reactive radicals promoting chemical reactions [222]. The physical effects of ultrasound induced by acoustic cavitation can boost the disruption of oil droplets, facilitating the formation of stable O/W [223]. High power ultrasound has mechanical, chemical and/or biochemical effects, which are used to modify the and enhance the quality of various food systems during processing [224].

VII. ADVANTAGES OF NANO EMULSIONS [225 - 230]

Nanoelums have a number of advantages due to the small size of their droplets (100 nanometers), most notably low cost, transparent appearance, no clumping or settling, and a large surface area, Non-toxic and non-irritating, therefore it can be taken via the digestive system. It has a superior ability to improve the solubility of hydrophobic substances, it can also be given topically, intravenously, by inhalation, nasally, intramuscularly, or orally, the metallic and bitter flavors of medicines that may cause unwanted side effects such as nausea and vomiting can be successfully masked using nanoemulsifiers. Nanoemulsifier formulations protect the active ingredients from degradation, oxidation, or reactions with external factors, such as light or heat, and the possibility of altering their rheological properties.

VIII. DISADVANTAGES OF NANO EMULSIONS [231- 237]

The stability of nanoemulsions is affected by environmental factors such as temperature and pH, and these factors change when nanoemulsions are given to patients, the homogenization apparatus (the tool needed to prepare nanoemulsions) is also an expensive process, and Ostwald maturation is the main problem associated with the non-acceptance of nanoemulsion formulations. Additionally, stabilizing nanodroplets requires the use of a high concentration of surfactants and auxiliary materials.

IX. APPLICATIONS OF NANO EMULSIONS [238-244]

Nanomulants appear highly attractive from an industrial perspective, given their ease of large-scale production and the absence of complex manufacturing techniques. Nanoemulsions have potential applications in the food industry for delivering pharmaceutical nutrients, coloring and flavoring agents, and antibiotics. Delivery systems made from smart materials with adjustable physical and biological properties also enhance current treatment methods. The development of nanosystems has shown a significant impact in many agricultural fields, including pesticide formulations, food coatings, fungicides, and antiparasitics. Recently, nanoemulsions have gained increasing importance as potential means of delivering cosmetics in a controlled manner, and of optimally distributing active ingredients in different layers of the skin.

X. RECOMMENDATIONS

The most important recommendations for developing nanoemulsions include improving their physical stability by using surfactants (non-toxic, safe, environmentally friendly), adopting high-energy production methods (ultrasonic homogenization), integrating artificial intelligence to improve formulations, and applying packaging techniques (drug loading and release), using Metal-organic frameworks in the preparation of crystalline nanocomposites because they have a large surface area, and have high porosity.

XI. CONCLUSION

To date Nano emulsions have been shown to be able to protect labile drug, control drug release, increase drug solubility,. The main thing is that it contain small particle size reduced to the nonmetric scale shows various physical properties. Nano emulsion can be used in various disciplines including cosmetics, biotechnology, food, agriculture and, and pharmaceuticals.

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Biotechnological Innovations in Insect Pest Management: From RNAi to CRISPR

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***Abstract*— *The increasing resistance of insect pests to conventional chemical insecticides, coupled with environmental and human health concerns, has necessitated the development of innovative and sustainable pest management strategies. In this context, biotechnological approaches have emerged as powerful tools for precise and eco-friendly insect pest control. This review comprehensively examines recent advances in biotechnological innovations for insect pest management, with a particular focus on RNA interference (RNAi) and CRISPR-Cas–based genome editing technologies. RNAi has demonstrated significant potential through sequence-specific gene silencing, offering targeted pest suppression with minimal non-target effects, although challenges related to delivery efficiency, stability, and resistance development remain. CRISPR-Cas technology represents a transformative advancement, enabling precise genome modifications for functional genomics, population suppression, gene drive systems, and the development of pest-resistant crop varieties. In addition to RNAi and CRISPR, the review highlights complementary biotechnological tools such as transgenic crops expressing insecticidal proteins, marker-assisted selection, and symbiont-mediated pest control strategies. The regulatory, biosafety, and ethical considerations associated with the deployment of these technologies are also discussed. Finally, the review emphasizes future prospects and research priorities for integrating biotechnological innovations into integrated pest management (IPM) programs to achieve sustainable and resilient agricultural production. Overall, the advancements discussed underscore the critical role of biotechnology in shaping the next generation of insect pest management strategies.*

Keywords*— *Insect pest management; Biotechnology; Bacillus thuringiensis; Transgenic crops; RNA interference (RNAi); CRISPR/Cas9; Host plant resistance; Integrated pest management

Introduction

The rapid expansion of the global population necessitates a substantial increase in both the quantity and quality of food production. However, agricultural productivity is significantly constrained by insect pests, which are responsible for approximately 18% of global crop losses, excluding additional damage caused by plant diseases and weeds (Oerke, 2006:sharma *et al*., 2017). In the absence of effective control measures, yield reductions can reach nearly 50% in wheat and more than 80% in cotton production [Oerke, 2006:sharma *et al*., 2017]. Therefore, effective insect pest management remains a critical requirement for ensuring food security and agricultural sustainability.

Since the 1950s, insect pest control has relied predominantly on so-called "conventional" synthetic insecticides. These chemicals revolutionized agricultural production during the mid-20th century and were widely adopted due to their remarkable effectiveness. However, in recent decades, Integrated Pest Management (IPM) has emerged as a more sustainable and ecologically sound approach, producing satisfactory outcomes despite practical challenges [Deguine *et al*., 2021:Zhou *et al*., 2024]. Ideally, IPM follows a three-layered pyramidal structure. The foundation consists of cultural practices, field manipulation, and the use of resistant host plants. The second tier incorporates biological and microbiological control agents, semiochemicals, and emerging biotechnological tools. Chemical control serves as the final option and is applied only when necessary.

The continuous pressure exerted by insect pests necessitates the development of effective management strategies that minimize environmental damage and reduce reliance on chemical pesticides (Gurr *et al*., 2004). Historically, insect pest management has evolved considerably. Early control methods involved manual removal and destruction of insects, followed by cultural and biological strategies. The discovery and widespread adoption of chemical insecticides in the mid-1940s revolutionized agricultural industries during the 1950s and early 1960s. Their unparalleled effectiveness led to extensive use, increasing food production and controlling insect-borne diseases. However, excessive reliance on chemical pesticides eventually resulted in what became known as the "Chemical crisis," characterized by escalating application rates due to the development of insect resistance ("History of IPM" n.d.). Public awareness of the environmental consequences of pesticide overuse increased significantly after the publication of *Silent Spring* in 1962 (Unsworth 2010).

Growing recognition of the adverse effects associated with heavy pesticide use shifted attention toward more comprehensive pest management strategies, leading to the formal adoption of Integrated Pest Management (IPM) in agriculture during the 1970s ("History of IPM" n.d.). IPM is defined as a multifaceted pest management approach that integrates various control strategies to maintain pest populations at tolerable levels while minimizing environmental impact (Alston 2011). Since its establishment, IPM has been widely regarded as one of the most effective and sustainable frameworks for insect pest management. Nevertheless, IPM is not without limitations. Many of these limitations arise from the difficulty in identifying and implementing the most appropriate combination of tactics under diverse agroecological conditions. These challenges have driven continued research efforts and stimulated the development of advanced biotechnological approaches for more precise and sustainable insect pest management.

In this review, we will explore emerging biotechnological approaches for insect pest management, highlighting their mechanisms, applications, and potential contributions to modern sustainable agriculture.

CRISPR-Cas9 Applications for Insect Pest Management

CRISPR-Cas9 has emerged as a highly promising tool in modern insect pest management (Mir *et al*., 2018). This genome-editing technology enables precise and targeted modification of genetic material, thereby offering significant opportunities for the development of pest-resistant crops, genetically engineered biological control agents, and direct genetic manipulation of pest populations. CRISPR (Clustered Regularly Interspaced Short Palindromic Repeats) systems represent a next-generation genetic control strategy with broad potential applications in sustainable agriculture.

In the context of insect pest management, CRISPR-Cas9 technology is being explored for several innovative applications, including gene drive systems, induction of sex-specific sterility, and the development of pest-resistant crop varieties. These approaches provide highly specific, efficient, and potentially long-term solutions for controlling economically important insect pests while reducing reliance on conventional chemical insecticides.

Gene drive systems and related CRISPR applications

One of the most promising applications of CRISPR in pest management is the development of gene drive systems, which are gene-editing technologies designed to increase the probability that a specific gene is inherited by offspring through biased inheritance, thereby enabling the rapid spread of desirable traits within populations (Lei-Chen et al. 2016). Drawing on the idea of selfish genetic elements that promote their own transmission regardless of host benefit (McFarlane et al. 2018), CRISPR-based gene drives have been engineered to introduce traits such as sterility or disease resistance, facilitating their swift propagation across generations (Hammond et al. 2016). Through targeted gene editing in pest species, gene drives can disseminate characteristics like infertility or reduced disease transmission; a well-known example involves malaria-resistant mosquitoes, where gene drives impair the insects' capacity to transmit the pathogen (Curtis, 1968). These CRISPR-mediated modifications are inherited by nearly all progeny, leading to rapid suppression of pest populations and improved control of vector-borne diseases. Advances in site-specific genome editing have enabled successful demonstrations of gene drives in yeast (DiCarlo et al., 2015), flies (Gantz and Bier, 2015), and mosquitoes (Gantz et al., 2015), underscoring the broad applicability of this strategy for population management. Overall, CRISPR-based gene drives represent a potent approach for pest suppression, disease mitigation, and conservation, expanding genetic control strategies across diverse species (Esvelt et al., 2014; Webber et al., 2015).

In addition to gene drives, CRISPR/Cas9 technology has significantly improved the sterile insect technique (SIT) by enabling precise modification of reproduction-associated genes to induce sterility with minimal off-target effects; editing sex-specific or fertility-related genes generates sterile individuals whose mating with wild counterparts produces non-viable offspring, progressively reducing pest populations. Diseases such as yellow fever, dengue, chikungunya, and Zika are transmitted by Aedes aegypti Linnaeus (Qsim et al., 2017), and traditional SIT methods relied on releasing radiation-sterilized males to compete with wild males (Benedict and Robinson, 2003; Shaw and Catteruccia, 2019; Dame et al., 2009), whereas CRISPR now enables targeted gene knockouts, such as β2-tubulin (B2t) mutation in A. aegypti causing complete male infertility (Chen et al., 2021). Similarly, CRISPR disruption of sex-specific doublesex (dsx) variants in Spodoptera frugiperda J.E. Smith reduced fecundity and fertility (Gu et al., 2022), while editing Serine protease 2 (Ser2) in Spodoptera litura Fabricius induced male sterility without affecting females (Bi et al., 2022). In Bombyx mori Linnaeus, mutation of BmSfp62 impaired sperm motility and altered seminal protein gene expression, leading to male sterility (Xu et al., 2022), and knockout of Hcdsx in Hyphantria cunea caused genital abnormalities, partial sex reversal, and reduced fecundity through altered splicing and downstream gene expression (Li et al., 2020). Furthermore, CRISPR-mediated genetic modification of natural enemies can enhance biological control by improving traits such as feeding efficiency or reproductive capacity, as demonstrated in parasitic wasps (Bai et al., 2024), with cinnabar and vermilion frequently targeted for phenotypic studies (Liu et al., 2017; Zhang et al., 2024). In Harmonia axyridis Pallas, which exhibits multiple elytral colour forms (Gautier et al., 2018; Xiao et al., 2020) and preys on aphids (Osawa, 2000; With et al., 2002) synchronizing oviposition with aphid peaks (Hironori and Katsuhiro, 1997; Osawa, 2000), editing the dopa decarboxylase (DDC) gene resulted in melanin-deficient mutants with extended development yet increased predation (Wu et al., 2022). Additionally, CRISPR/Cas9 offers a precise alternative to conventional breeding for pest-resistant crops, which is often laborious and time-consuming (Scheben et al., 2017); initiatives such as the i5k project have generated extensive genomic resources for insects (Thomas et al., 2020; Majhi et al., 2023), supporting identification of novel targets for CRISPR-based crop protection. CRISPR enables modification of plants to enhance resistance against pests (Wang et al., 2018a) and supports development of pest- and disease-resistant genotypes (Molla et al., 2021), with edited crops demonstrating improved resistance to pests such as Chilo suppressalis and Nilaparvata lugens, thereby reducing reliance on chemical pesticides.

RNA Interference

Extensive research has been conducted on the application of RNA interference (RNAi) as a highly specific strategy for insect pest control [Zhu *et al*., 2020]. RNAi is a conserved molecular mechanism present in nearly all eukaryotic organisms and is responsible for sequence-specific gene silencing. The process is initiated by double-stranded RNA (dsRNA), either exogenous or endogenous, that is homologous to a target gene. Once inside the cell, dsRNA molecules are processed into small interfering RNAs (siRNAs) of approximately 21–23 nucleotides in length. These siRNAs are subsequently incorporated into the RNA-induced silencing complex (RISC), which utilizes the siRNA as a guide to recognize and degrade complementary messenger RNA (mRNA), thereby suppressing expression of the target gene [Meister and Tuschl, 2024].

Despite its considerable potential, RNAi efficiency varies significantly among different insect orders. It has been shown to be highly effective in Coleoptera, whereas its efficacy in Lepidoptera is comparatively lower. Intermediate and variable responses have been reported in Hemiptera and Diptera (Christiaens *et al*., 2021:, Cooper et al., 2019; He et al 2022). This variability is largely attributed to intrinsic biological factors, particularly differences in cellular uptake mechanisms and intestinal degradation of dsRNA (Christiaens *et al*., 2021).

Numerous studies have demonstrated the potential of RNAi-based approaches in insect pest management, and selected examples are summarized in Table 1.

Table 1. RNAi-mediated gene silencing in insect pests and target crops

Sr. No.	Target insects	Silenced gene	Target crop	References
1	*Diabrotica virgifera virgifera* LeConte	Suppression of target mRNA	Maize	Baum *et al*. (2007)
2	*Diabrotica v. virgifera*	*hunchback* (hb) and *brahma* (brm) gene	Maize	Khajuria *et al*. (2015)
3	*Leptinotarsa decemlineata*	β-actin gene	Potato	Zhang *et al*. (2015)

4	Lepidopteran	dsRNA spray	Maize	Li *et al*. (2015)
5	*Helicoverpa armigera*	Chitinase gene (*HaCHI*)	Tomato, Tobacco	Mamta *et al*. (2016)
6	*Chilo suppressalis*	Aminopeptidase N genes (*APN1* + *APN2*)	Rice	Qiu *et al*. (2017)
7	*Leguminivora glycinivorella*	SppPO-dsRNA	Soybean	Meng *et al*. (2017)
8	*Helicoverpa armigera*	Juvenile hormone methyl transferase (JHMT)	Cotton	Ni *et al*. (2017)
9	*Diabrotica virgifera virgifera* LeConte	*Dvvrgr*, *dvbol*	Maize	Niu *et al*. (2017)
10	*Leptinotarsa decemlineata*	*ECR* gene	Potato	Hussain *et al*. (2019)
11	*Scirpophaga incertulas*	*AChE* – Acetylcholine esterase	Rice	Kola *et al*. (2019)
12	*Manduca sexta*	*v-ATPaseA* gene	Tobacco	Burke *et al*. (2019)
13	*Bemisia tabaci*	*BATCTB* gene	Tobacco	Dong *et al*. (2020)
14	*Aphis glycines*	*TREH, ATPD, ATPE, CHSI*	Soybean	Yan *et al*. (2020)
15	*Bemisia tabaci*	Phenolic glucoside malonyltransferase	Tobacco	Xia *et al*. (2021)
16	*Spodoptera littoralis*	Sl 102 immune gene	Tobacco	Di Lelio *et al*. (2022)

Marker-Assisted Selection

The use of molecular markers to assist phenotypic selections in crop improvement is known as marker-assisted selection (MAS). It involves selecting individuals based on their marker pattern (genotype) rather than their observable traits (phenotype) as shown in Fig 1. There are various types of molecular markers, such as single nucleotide polymorphism (SNP), have been recognised and have shown great promise in enhancing the efficiency and accuracy of conventional plant breeding. Molecular marker techniques are the most advanced method for transferring desired genes into desired crop plants in the required combination. It is the most widely used molecular techniques, and their application is a novel opportunity for increasing the yield of crop (Das *et al*., 2017). MAS studies showed introgression of *Bph14* and *Bph15* through molecular marker-assisted selection (MAS) to enhance the resistance in Minghui 63 and its derived hybrids against BPH (Hu *et al*., 2012). Resistance to bacterial blight (BB) and brown planthopper (BPH) was achieved in Yuehui9113 and F1 hybrids by pyramiding one BB resistance gene (*Xa21*) and two BPH resistance genes (*Bph14 and Bph15*) in Yuehui9113 using a marker-assisted backcrossing (MABC) strategy combined with phenotypic selection (He *et al*., 2019). Rice line, ASD7 expressing a BPH resistance gene *bph2* when crossed to a susceptible cultivar C418, a japonica restorer line and evaluated through marker-assisted selection (MAS) exhibited significantly higher resistance against brown plant hopper *Nilaparvata lugens,* one of the most destructive pests of rice crop (Li-Hong *et al*., 2006). Liu *et al*. (2016) investigated that the pyramiding of two brown plant hopper resistance genes *Bph3* and *Bph27* (t), into elite rice cultivars through marker-assisted pyramiding showed significantly enhanced resistance against BPH and reduction in the yield loss caused by BPH. Shabanimofred *et al*. (2015) developed rice cultivars through marker-assisted selection (MAS) that provided resistance in rice against biotypes 2 and 3 of brown plant hopper (BPH). Sharma *et al*. (2004) used marker-assisted pyramiding to successfully construct the *Bph1* and *Bph2* resistance genes on rice chromosome 12 to provide resistance against rice BPH. *et al*. As a result, using MAS to improve pest resistance would be very beneficial. There are various advantages of using MAS to enhance selection efficiency of insect resistant plants 1) It can be performed on seedling material, 2) less affected by environmental conditions, 3) MAS may be cost effective and faster than conventional phenotypic assays, 4) multiple markers can be evaluated using the same DNA sample etc. But the potential drawbacks of MAS are 1) Recombination between the marker and the gene of interest may occur, leading to inaccurate results 2) Incorrect estimates of QTL locations and effects may result in slower progress than expected, 3) Markers developed for MAS in one population may not be transferrable to other populations.

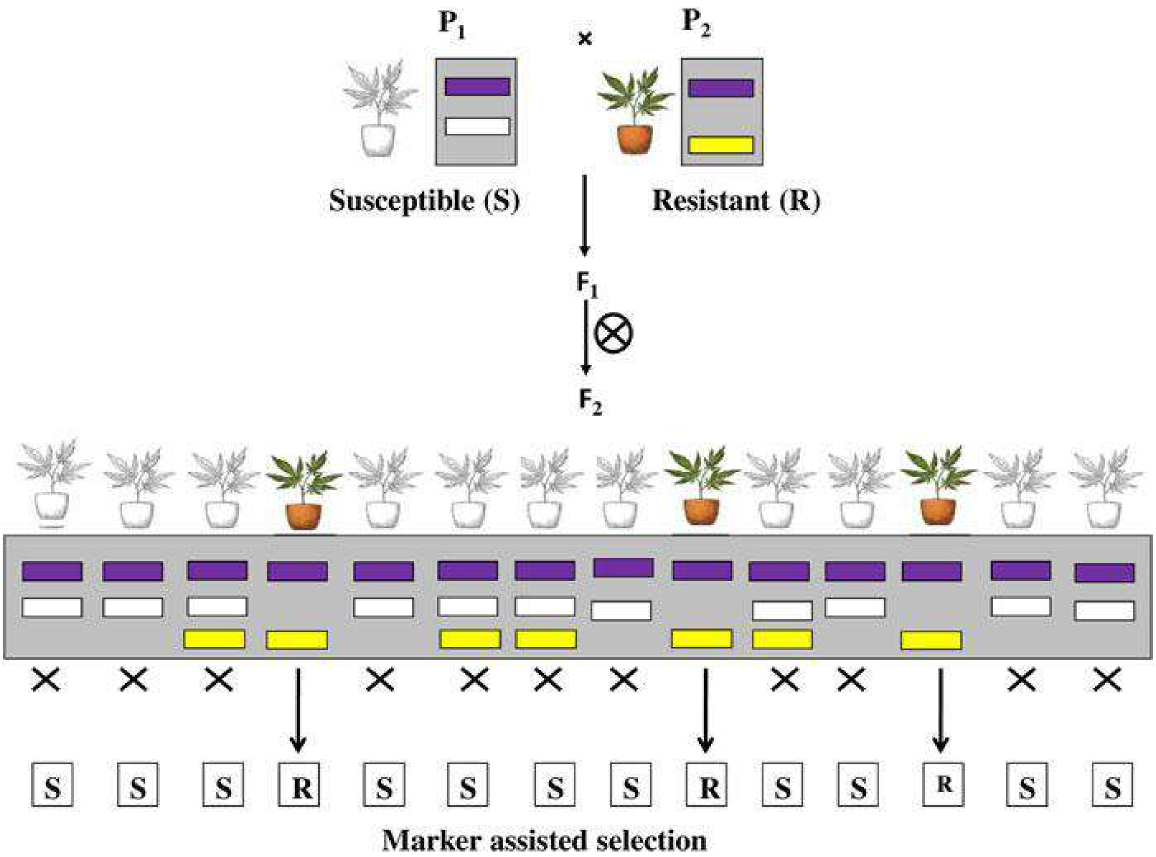

Fig. 1: Marker assisted selection

Gene Transformation

Gene transformation, also referred to as genetic engineering of crops for insect resistance, involves the incorporation of specific DNA segments or genes into crop plants to confer protection against insect pests. The introduced DNA sequences typically encode proteins possessing insecticidal activity. Resistance in plants is achieved through the expression of these insecticidal proteins derived from the inserted genetic material, thereby providing targeted protection against specific insect pests (Gatehouse, 2013).

This technology has been evaluated against a broad spectrum of insect pests belonging to the orders Lepidoptera, Coleoptera, and Diptera (Birkett and Pickett, 2014). Among the most successful applications of genetic transformation is the development of genetically modified crops expressing insecticidal proteins from *Bacillus thuringiensis* (Bt), a soil-dwelling bacterium. Since their commercial introduction in 1996, Bt crops have been extensively cultivated worldwide and have played a significant role in modern agricultural pest management (Abbas, 2018).

The cry gene transformation technology involves the transfer of specific DNA sequences encoding Cry proteins into crop plants through methods such as Agrobacterium-mediated transformation or particle bombardment (Juturu *et al*., 2015). These transformation techniques enable stable integration and expression of insecticidal genes within the plant genome, resulting in enhanced resistance to target insect pests.

Cry Genes

Bacillus thuringiensis (*Bt*) is a Gram-positive soil bacterium expressing insecticidal crystalline proteins (ICPs) that are exceptionally toxic to specific classes of pests (Panwar *et al*., 2018). Insecticidal activity in insect-resistant *Bt* crops is expressed by the genes coding for parasporal crystal protoxins (Palma *et al*., 2014). ICPs produced by transgenic plants have had a significant impact on the successful evolution of insect resistance. The crystal involves a protoxin protein which get solubilized in the larval midgut due to alkaline pH and subsequently cleaved enzymatically to an active toxin. The toxin diffuses through the peritrophic membrane covering the gut and binds to receptors present in the midgut epithelium (Paul and Das, 2020) making pores in the midgut epithelium. The gut gets paralyzed and then the pest stops feeding and dies within 2–3 days (Figure 2).

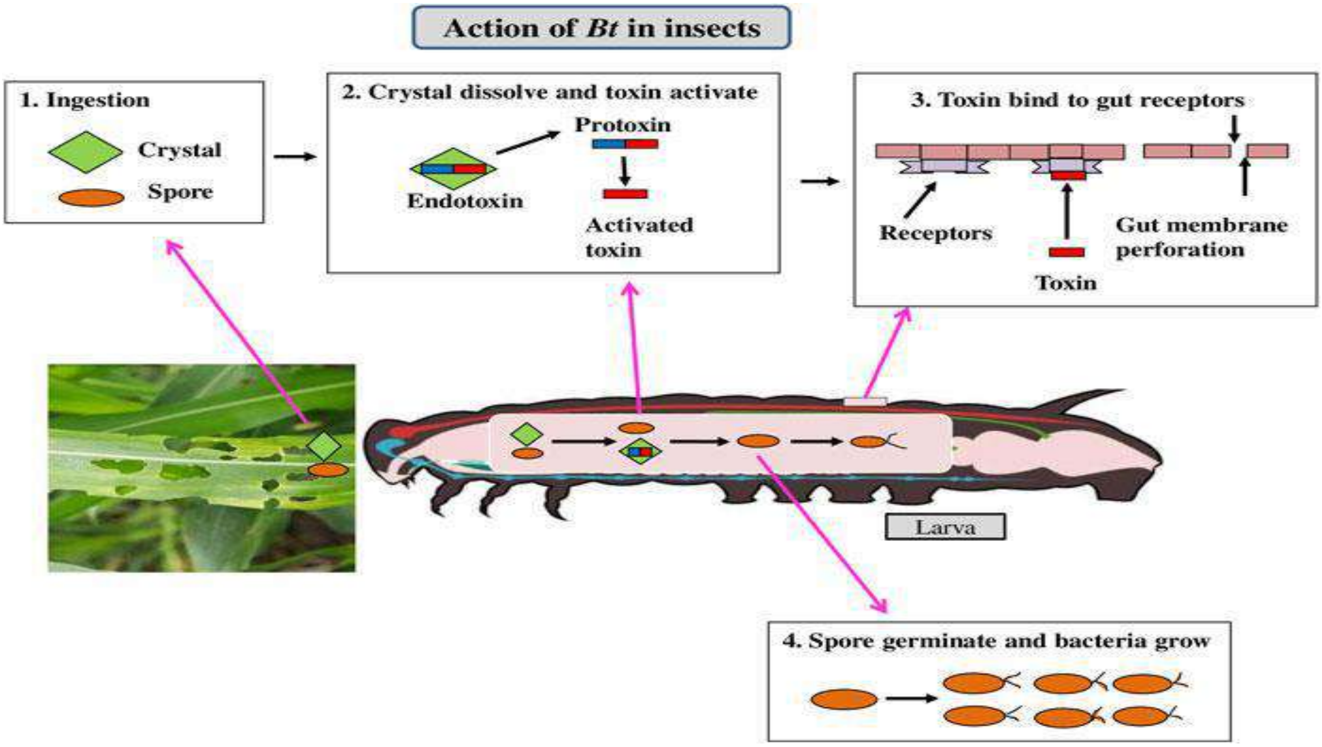

Fig. 2: Action of Bt. In insects

The first-generation Bt cotton, Bollgard I (BG I), expressing *cry1Ac*, was commercialized and released in 2002 for the management of major bollworm species, including *Pectinophora gossypiella*, *Earias vittella*, and *Helicoverpa armigera*, in cotton-growing regions of India. Subsequently, Bollgard II (BG II) was introduced in 2006 as a second-generation Bt cotton containing pyramided traits expressing *cry1Ac* and *cry2Ab* (MON15985 event). At present, BG II occupies nearly 95% of the total cotton cultivation area in India. Compared with BG I, which expresses only *cry1Ac*, BG II harboring both *cry1Ac* and *cry2Ab* demonstrates enhanced efficacy in pest management (Carrière *et al*., 2015).

Another transgenic cotton variety, WideStrike cotton expressing *cry1Ac* + *cry1F*, was approved in the USA in 2004 by Dow AgroSciences, contributing to improvements in both crop yield and farmers' income. Both BG II and WideStrike cotton, with pyramided gene constructs, exhibit broader and more effective suppression of Lepidopteran, Coleopteran, and Dipteran pests than BG I.

Additionally, transgenic cotton containing *cry10Aa* displayed strong resistance against the cotton boll weevil (*Anthonomus grandis*), with 100% larval mortality observed in T1 generation bioassays following leaf consumption (Ribeiro *et al*., 2017). Agrobacterium-mediated transformation has also been used to develop cotton lines expressing pyramided *cry1Ac* and *cry2Ab* genes within the T-DNA region, resulting in 93% larval mortality of *S. litura* (Siddiqui *et al*., 2019). Furthermore, transgenic rice lines engineered to express the *cry2AX1* gene showed effective resistance against rice leaf folder (*C. medinalis*) and rice yellow stem borer (*S. incertulas*) (Rajadurai *et al*., 2018).

Transgenic cotton and brinjal varieties resistant to borers were approved for commercial cultivation in Bangladesh, while insect-resistant Bt soybean expressing *cry1Ac* + *cry1Ab* was authorized for production in Latin America in 2014 (Koch *et al.,* 2015). In another study, the introduction of a synthetic *cry1Ab* gene into tomato conferred effective resistance against the tomato leaf miner, *T. absoluta*, resulting in 100% mortality at the T0 generation within 4–5 days (Soliman et al., 2021). Rice variety Bg94–1 developed through the transfer of the *cry2A* gene exhibited approximately 80% mortality in rice leaf folder populations (Gunasekara *et al*., 2017).

Similarly, transgenic pigeon pea lines engineered with a combination of *cry1Ac* and *cry2Aa* demonstrated resistance to *H. armigera*, achieving 80%–100% larval mortality (Ghosh *et al.,* 2017). Expression of the *cry1Aa* gene in sweet potato provided resistance against the lepidopteran pest *Spodoptera litura* (Zhong *et al.,* 2019). In cotton event CH12, expression of the *cry2AX* gene resulted in 88% mortality of *H. armigera* at the T0 generation (Sakthi *et al*., 2015), while expression of *cry2AXI* in the T3 generation of the same event produced 90% mortality (Jadhav *et al*., 2020).

An industrially important non-edible castor developed through Agrobacterium-mediated transfer of the *cry1Aa* gene exhibited strong resistance against two lepidopteran pests, *Achaea janata* and *S. litura* (Muddanuru *et al.*, 2019). Transgenic soybean expressing a *cry8*-like gene derived from *B. thuringiensis* conferred resistance to the coleopteran pest *Holotrichia parallela* (Qin *et al.*, 2019). The transgenic cotton event MNH93 carrying *cry1Ab* showed 40–60% larval mortality against *H. armigera*, with a transformation frequency of 0.26% (Khan *et al.*, 2011). Additional Bt-derived proteins, such as *cyt2Aa*, have been reported to provide resistance against aphids (Chougule *et al.,* 2013), while *cry51Aa2* increased mortality of *Lygus* species in cotton (Gowda *et al.*, 2016). The expression of cry genes across different crop species is summarized in Table 2.

Despite the successful application of cry gene technologies in developing insect-resistant crops, the evolution of resistance in target pest populations remains a major concern and can significantly threaten crop productivity. Other challenges limiting the long-term effectiveness of transgenic crops include secondary pest outbreaks, emergence of new pest biotypes, potential impacts on non-target organisms, environmental effects on transgene expression, biosafety concerns related to genetically modified foods, and various socio-economic and ethical considerations. Therefore, further research is needed to better understand plant–insect interactions and the mechanisms underlying resistance development in insects against cry genes.

Table 2. Transgenic crops carrying Bt genes for insect resistance.

S. No.	Target insects	Transgene	Target crop	References
1	*Chilo suppressalis*, *Cnaphalocrocis medinalis*	*cry1Ab*	Rice	Fujimoto *et al.* (1993)
2	*Scirpophaga incertulas* & *Chilo suppressalis*	*cry1Ab*	Rice	Wünn *et al.* (1996)
3	*Scirpophaga incertulas*, *Cnaphalocrocis medinalis*	*cry1Ab*	Rice	Ghareyazie *et al.* (1997)
4	*Scirpophaga incertulas*	*cry1Ac*	Rice	Nayak *et al.* (1997)
5	*Scirpophaga incertulas*	*cry1Ab/cry1Ac*	Rice	Tu *et al.* (2000)
6	*Cnaphalocrocis medinalis*, *Scirpophaga incertulas*	*cry2A/cry1Ac*	Rice	Maqbool *et al.* (2001)
7	*Helicoverpa armigera*	*cry1Ab + NptII*	Cotton	Khan *et al.* (2011)
8	*Heliothis* sp.	*cry1Ab*	Cotton	Khan *et al.* (2013)
9	*Helicoverpa armigera*	*cry2AX*	Cotton	Sakthi *et al.* (2015)
10	*Helicoverpa armigera*	*cry1Ac* + *cry2Aa*	Pigeon pea	Ghosh *et al.* (2017)
11	*Helicoverpa armigera*	*cryIIAa*	Chickpea	Sawardekar *et al.* (2017)
12	*Cnaphalocrocis medinalis*	*cry2A*	Rice	Gunasekara *et al.* (2017)
13	*Tuta absoluta*	*cry1Ac*	Tomato	Selale *et al.* (2017)
14	*Anthonomus grandis*	*cry1Aa*	Cotton	Ribeiro *et al.* (2017)
15	*Helicoverpa armigera*	*cry2Aa*	Pigeon pea	Baburao & Sumangala (2018)
16	*Helicoverpa armigera*	*cry2Aa*	Pigeon pea	Singh *et al.* (2018)
17	*Scirpophaga incertulas*, *Cnaphalocrocis medinalis*	*cry2AX1*	Rice	Rajadurai *et al.* (2018)
18	*Spodoptera litura*	*cry1Aa*	Sweet potato	Zhong *et al.* (2019)
19	*Spodoptera litura*	*cry1Ac* + *cry2Ab*	Cotton	Siddiqui *et al.* (2019)

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20	*Holotrichia parallela*	*cry8*-like	Soybean	Qin *et al*. (2019)
21	*Achaea janata*, *Spodoptera litura*	*cry1Ac*	Castor	Muddanuru *et al*. (2019)
22	*Helicoverpa armigera*	*cry2AX1*	Cotton	Jadhav *et al*. (2020)
23	*Tuta absoluta*	*cry1Ab*	Tomato	Soliman *et al*. (2021)

Conclusion and Future Outlook

Insect pests continue to represent one of the most significant constraints to global agricultural productivity. Historically, farmers have relied heavily on chemical insecticides due to their rapid and visible effectiveness. However, increasing awareness of the adverse impacts of indiscriminate pesticide use on human and animal health, biodiversity, and environmental quality has intensified the search for safer and more sustainable pest management strategies. Within this framework, host plant resistance has emerged as an environmentally sound and economically viable cornerstone of Integrated Pest Management (IPM) programmes. The development and deployment of insect-resistant crop varieties provide long-term and cumulative suppression of pest populations while minimizing ecological disruption.

Substantial progress has been achieved in identifying resistant germplasm sources across diverse crop species. Nevertheless, conventional breeding for insect resistance remains laborious and time-intensive, particularly because many resistance traits are quantitatively inherited and controlled by multiple loci. Recent advances in biotechnology have revolutionized this field by offering precise, efficient, and multi-mechanistic approaches for pest control. Modern biotechnological tools facilitate the introduction of insecticidal genes, novel bioactive compounds, and engineered gene expression systems to enhance plant defence responses beyond the limitations of traditional breeding.

Several insect-resistant crops developed through biotechnological interventions—including maize, rice, cotton, canola, soybean, tobacco, apple, and potato—have demonstrated effective protection against economically destructive insect pests. The integration of advanced techniques such as genetic transformation, genome editing, marker-assisted selection, somaclonal variation, anther culture, embryo culture, and protoplast fusion is expected to further accelerate the development of improved resistant cultivars. The expression of bacterial delta-endotoxins, vegetative insecticidal proteins, and endogenous plant defence molecules such as lectins and protease inhibitors has significantly enhanced resistance levels in a shorter timeframe compared to conventional approaches.

More recently, RNA interference (RNAi) and CRISPR/Cas9-mediated genome editing have emerged as highly promising technologies for targeted and precise insect pest management. These approaches enable the silencing or modification of genes critical for insect survival, development, reproduction, or plant–insect interactions, thereby offering new opportunities for durable and species-specific resistance. Despite these technological advancements, the rapid evolution of resistance in insect populations against insecticidal toxins remains a persistent challenge that threatens the sustainability of current strategies.

Future research must prioritize a deeper mechanistic understanding of plant–insect interactions and resistance evolution to enhance the durability of engineered traits. The development of gene pyramiding strategies, resistance management frameworks, and integrated deployment within IPM systems will be essential to delay resistance development. Furthermore, comprehensive environmental risk assessments—particularly regarding impacts on non-target organisms and ecosystem dynamics—are critical prior to commercial release.

In addition to scientific considerations, socioeconomic and regulatory dimensions must not be overlooked. The implications of adopting biotechnological solutions, especially for smallholder and resource-limited farmers in developing countries, require careful evaluation. Robust regulatory frameworks, transparent risk–benefit analyses, and active engagement among researchers, policymakers, producers, and consumers are essential for responsible implementation. Public awareness and open dialogue will play a decisive role in fostering trust and acceptance of these emerging technologies.

In conclusion, biotechnology represents a powerful and transformative tool for advancing sustainable insect pest management. By enhancing crop resistance, reducing dependence on chemical pesticides, lowering production costs, and strengthening global food security, biotechnological innovations hold immense promise. When deployed responsibly, ethically, and within comprehensive regulatory and ecological safeguards, these approaches can substantially contribute to addressing current and future pest management challenges in agriculture.

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Beyond Production: Inland Fisheries as a Nutrition-Sensitive Food System in Jharkhand, India

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Abstract— *Inland fisheries and aquaculture represent a vital, yet underutilized, nutrition-sensitive food system with significant potential to address dual challenges of malnutrition and rural poverty. This review synthesizes scientific and socio-economic evidence to evaluate this dual role in the resource-rich but malnutrition-affected state of Jharkhand, India. An analysis of published nutritional data reveals that commonly consumed freshwater fish species are rich sources of high-quality protein (10–22%), essential long-chain omega-3 fatty acids (EPA and DHA), and critical micronutrients including bioavailable iron, calcium, zinc, and vitamins A and D. These attributes position freshwater fish as a potent dietary tool against anemia, stunting, and hidden hunger prevalent in the region. Economically, the sector supports thousands of rural households, yet state-level productivity (~2,570 kg ha^{-1} yr^{-1}) lags behind national benchmarks. Persistent constraints in seed quality, feed availability, and extension services limit sectoral performance. Our integrated analysis underscores that inland fisheries are not merely a production sector but a foundational component of sustainable food systems. We conclude by proposing a nutrition-sensitive fisheries framework for Jharkhand, advocating for policy interventions that concurrently enhance scientific aquaculture management, integrate fish into nutrition programs, and strengthen value chains to improve both health outcomes and economic security for vulnerable communities.*

Keywords— ***Inland fisheries; Nutrition-sensitive aquaculture; Food security; Micronutrients; Rural livelihoods; Jharkhand; Freshwater fish; Omega-3 fatty acids; Policy interventions; Sustainable food systems.***

I. INTRODUCTION

Global food systems are under increasing pressure to deliver nutritious diets sustainably while supporting economic livelihoods. Within this context, fish and fisheries are recognized as a critical component, contributing substantially to food and nutrition security, particularly in low- and middle-income countries (FAO, 2020). Fish provide a unique package of nutrients—high-quality protein, essential fatty acids, and bioavailable vitamins and minerals—that are often deficient in plant-based diets (Tacon & Metian, 2013). Over the past five decades, global per capita fish consumption has more than doubled, driven by recognition of its health benefits and its role in diverse food cultures (FAO, 2020).

Inland fisheries and aquaculture, often embedded within rural agrarian landscapes, play a disproportionately crucial role in developing regions. Unlike marine fisheries, these systems are directly accessible to rural populations, offering immediate opportunities for household food access and income generation (Béné et al., 2007). The consumption of small, indigenous freshwater fish species, often eaten whole, is especially valuable as it provides highly bioavailable calcium, iron, and vitamin A, directly targeting micronutrient deficiencies termed "hidden hunger" (Mohanty et al., 2016).

India, as the world's second-largest fish producer, relies heavily on its inland waters, which contribute the dominant share of total production (FAO, 2020). The fisheries sector is a significant economic driver, supporting over 14 million livelihoods (Murugan & Sivagnanam, 2018). However, this aggregate national success masks stark regional disparities. Jharkhand, an eastern Indian state endowed with abundant rivers, reservoirs, and ponds, presents a compelling paradox. Despite rich fisheries resources and a tradition of fish consumption, the state contends with alarmingly high rates of poverty, child stunting, and anemia (Raykar et al., 2015; FAO et al., 2021). This disconnect between resource potential and developmental outcomes signals a critical gap. Harnessing inland fisheries through an explicit nutrition-sensitive lens could therefore offer a sustainable pathway to simultaneously improve dietary quality and rural economic resilience.

This review aims to: (1) synthesize evidence on the nutritional composition and health relevance of freshwater fish in Jharkhand; (2) evaluate the economic contribution of inland fisheries to livelihoods and state development; and (3) identify constraints and propose evidence-based pathways for strengthening a nutrition-sensitive fisheries sector in the state.

II. MATERIALS AND METHODS

This study employs a structured narrative review methodology. A systematic search was conducted for peer-reviewed literature indexed in Scopus, Web of Science, and Google Scholar, using keywords including "freshwater fish nutrition," "inland fisheries," "aquaculture livelihoods," "Jharkhand," and "micronutrients." Official publications from the Food and Agriculture Organization (FAO) and fisheries statistics from the Government of Jharkhand (2010–2021) were incorporated to provide socio-economic context. Nutritional data extraction focused on the proximate composition, fatty acid profiles, and micronutrient content of predominant freshwater fish species. Economic analysis centered on production trends, productivity metrics, and employment data. The evidence was synthesized thematically to build an integrated assessment of the sector's dual role in nutrition and economics.

III. FISHERIES RESOURCES AND PRODUCTION CONTEXT OF JHARKHAND

Jharkhand's tropical monsoon climate and extensive network of rivers—including the Damodar, Subarnarekha, and Brahmani systems—support a significant inland water resource base exceeding 140,000 hectares, comprising reservoirs, check dams, and village ponds (Government of Jharkhand, 2019) (Figure 1). These water bodies form the foundation for capture fisheries and diverse aquaculture practices, including pond-based culture and cage aquaculture.

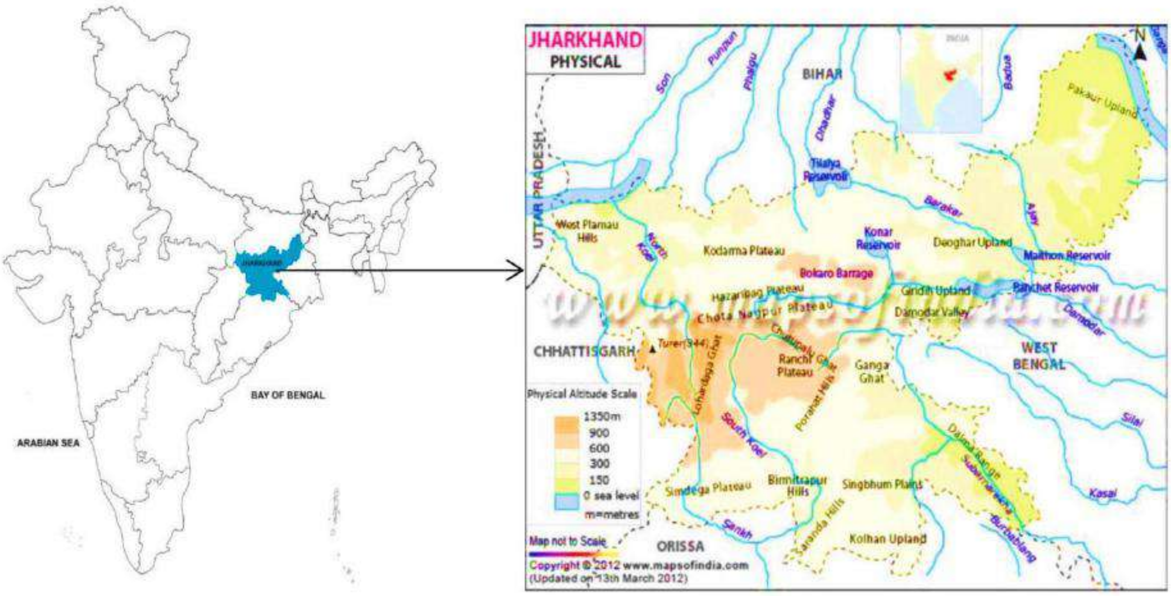

Fig.1 illustrates the spatial distribution of major inland water resources in Jharkhand, highlighting their potential for fisheries development.

Freshwater aquaculture in the state is dominated by Indian major carps (*Catla catla*, *Labeo rohita*, *Cirrhinus mrigala*) and exotic carps like silver carp and grass carp. Importantly, small indigenous species (SIS) and air-breathing fish (*Clarias batrachus*, *Channa* spp.) also contribute significantly to local diets, prized for their taste and nutritional value (Sankar et al., 2010).

Despite this potential, the sector operates below capacity. Current fish production (~223,000 metric tons in 2019-20) fails to meet domestic demand, necessitating substantial imports from other states (Prakash & Singh, 2016). The average productivity of 2,570 kg ha^{-1} yr^{-1} remains below the national average, highlighting a substantial yield gap and an opportunity for development.

IV. THE NUTRITIONAL PROFILE OF FRESHWATER FISH: A DIETARY POWERHOUSE

4.1. High-Quality Protein and Lipids

Freshwater fish are a rich source of digestible protein (10–22% of edible portion) with an excellent essential amino acid profile (Figure 2). This is particularly beneficial in Jharkhand, where diets are often cereal-based and lack adequate lysine and methionine—amino acids abundantly present in fish (Mohanty et al., 2019). The lipid content (1–20%) is characterized by a favorable profile of polyunsaturated fatty acids (PUFAs). While total lipid is generally lower than in marine fish, freshwater species provide physiologically significant amounts of long-chain omega-3 fatty acids, eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), known for their cardioprotective and neurodevelopmental benefits (Calder, 2004).

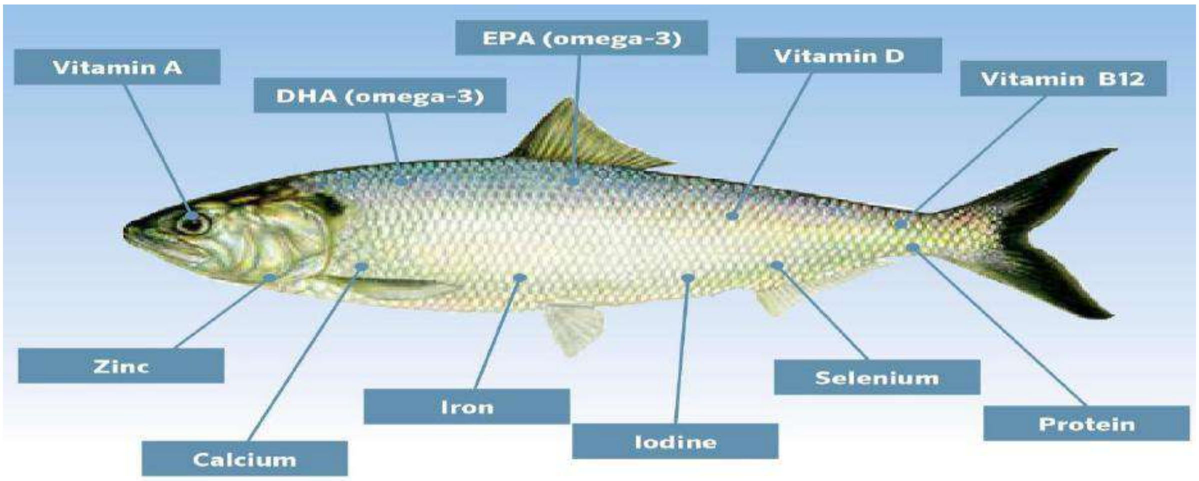

Fig.2 presents a comparative overview of the proximate composition of major freshwater fish species consumed in Jharkhand.

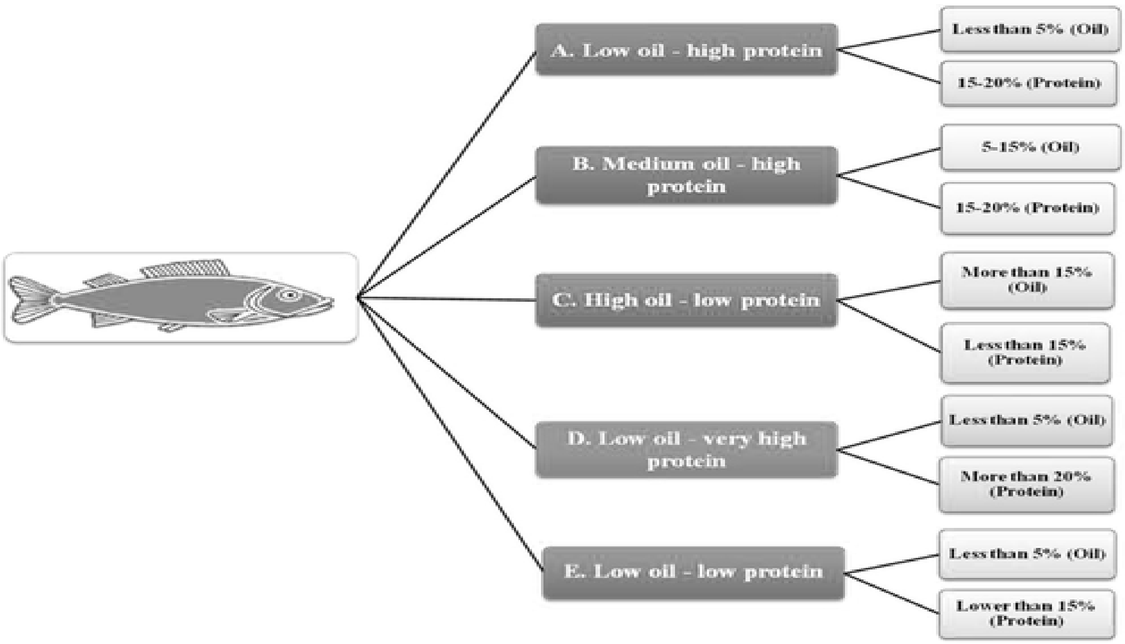

Fig.3 Summarizes the relative micronutrient density of selected freshwater fish species.

4.2. Critical Micronutrients for Combating Hidden Hunger

The most compelling nutritional argument for freshwater fish, especially SIS consumed whole, lies in their micronutrient density (Figure 3). They are excellent sources of bioavailable iron (1–3 mg/100g) and zinc (0.6–1.8 mg/100g). Crucially, consuming small fish with bones provides exceptionally high levels of calcium (200–1,500 mg/100g), offering a highly accessible solution to calcium deficiency (Malde et al., 2010). Furthermore, fish, particularly their livers and viscera, are important sources of fat-soluble vitamins A and D, essential for immune function, vision, and bone health.

V. RESULTS AND SYNTHESIS

5.1. Nutritional Significance in Local Context

The synthesized data confirm that freshwater fish available in Jharkhand can substantially contribute to filling nutrient gaps. Regular consumption can enhance protein quality and provide meaningful cumulative intakes of EPA and DHA. More directly, integrating SIS into daily diets represents a highly localized and sustainable strategy to combat the region's high prevalence of iron-deficiency anemia and calcium insufficiency.

5.2. Economic Contributions and Livelihoods

The fisheries sector is a vital source of livelihood for thousands, particularly among tribal and marginalized communities (Figure 4). Employment spans the value chain: from primary production in ponds and reservoirs to seed rearing, processing, and marketing. This makes the sector a critical buffer for rural economic security. However, the below-average productivity indicates systemic inefficiencies that curb greater income generation and sectoral growth.

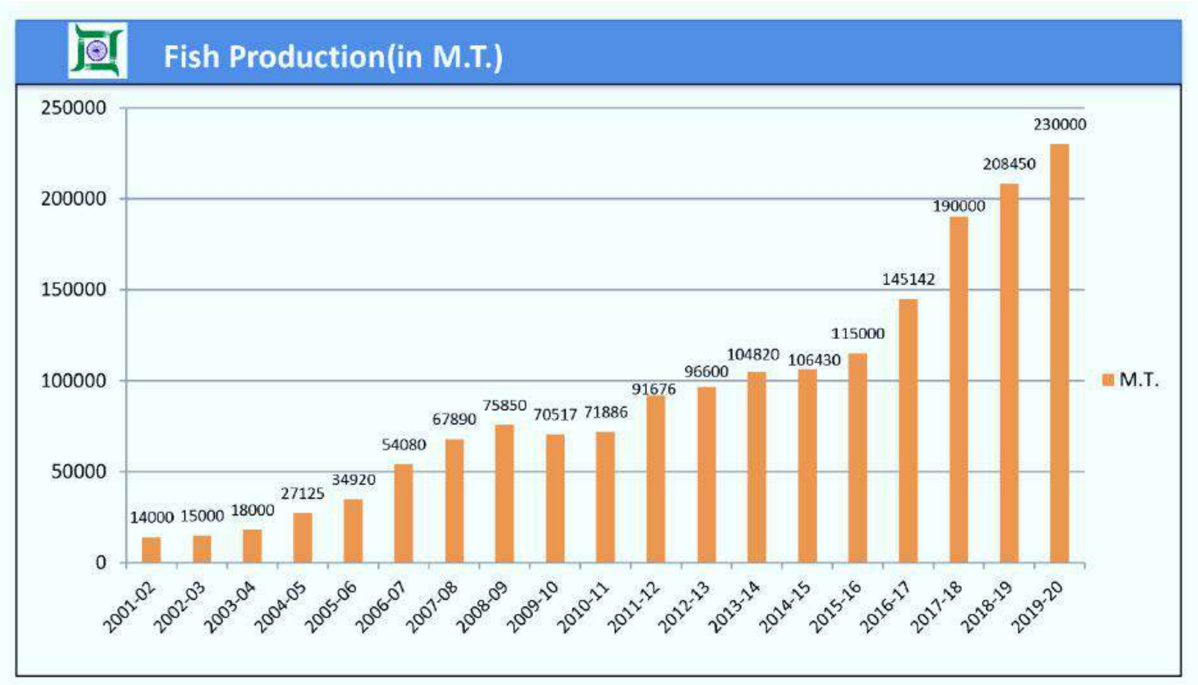

Fig.4 State-level inland fish production and productivity in Jharkhand

5.3. Identified Constraints

Key constraints hindering the sector mirror challenges across eastern India: inconsistent supply of quality fish seed, high cost and low availability of formulated feeds, weak technical extension services, and poor post-harvest infrastructure (Prakash & Singh, 2016; Cai et al., 2019). These factors collectively suppress yields, increase vulnerability, and limit the sector's potential economic and nutritional impact.

VI. DISCUSSION: TOWARDS A NUTRITION-SENSITIVE FISHERIES FRAMEWORK

This review establishes that inland fisheries in Jharkhand are at a nexus of nutrition security and economic development—a dual role that remains under-optimized. The evidence moves beyond viewing fish merely as a commodity for production, reframing it as an essential component of a healthy food system, particularly for vulnerable groups.

Our findings align with and contextualize global literature on nutrition-sensitive fisheries (Béné et al., 2007; FAO, 2020), but they ground the argument in the specific socio-ecological reality of Jharkhand. The high prevalence of malnutrition is not due to a lack of nutritional solutions within the local food system but rather to a lack of strategic focus on harnessing them. Simply increasing aggregate fish production will not automatically translate into better nutrition. Success requires ensuring that nutrient-rich fish (especially SIS) are accessible, affordable, and consumed by women and children in the first 1,000 days of life.

Economically, overcoming the identified constraints requires a shift from a focus on area expansion to one of productivity enhancement and value-chain efficiency. Strengthening hatchery networks, promoting cost-effective feed alternatives, and improving market access are essential to boost incomes and make fish more affordable for the poor.

VII. POLICY IMPLICATIONS AND FUTURE DIRECTIONS

To unlock the dual potential of inland fisheries, we propose the following integrated, nutrition-sensitive pathways for policy in Jharkhand:

1. **Promote Nutrient-Dense Species:** Actively integrate small indigenous fish species (SIS) into aquaculture extension programs and backyard pond models, emphasizing their nutritional superiority.
2. **Strengthen Input Systems:** Establish reliable, decentralized hatcheries for quality seed and support local production of affordable, farm-made feeds.
3. **Integrate with Nutrition Programs:** Link fisheries development with government nutrition safety nets (e.g., Mid-Day Meal Scheme, Integrated Child Development Services) to create guaranteed markets for small-scale fishers and farmers while improving child nutrition.
4. **Empower Women in Value Chains:** Facilitate women's access to resources for small-scale aquaculture and post-harvest processing, recognizing their pivotal role in household food and nutrition security.
5. **Invest in Climate-Resilient Practices:** Develop and disseminate aquaculture practices resilient to climate variability, ensuring the sector's sustainability.

Future research should prioritize longitudinal studies on the health impacts of fish consumption in tribal communities, detailed value-chain analyses to identify equity bottlenecks, and the development of climate-adaptive aquaculture technologies.

VIII. CONCLUSION

Inland fisheries and aquaculture in Jharkhand are not a peripheral activity but a cornerstone for sustainable and equitable development. This review demonstrates that the sector can simultaneously address the pressing challenges of malnutrition and rural poverty. Freshwater fish, as nutrient-dense foods, offer a direct dietary solution to micronutrient deficiencies, while the sector provides crucial livelihood opportunities. Realizing this potential requires a deliberate policy shift from a production-centric approach to a holistic, nutrition-sensitive framework. Strategic investments in technology, institutions, and inclusive governance can transform Jharkhand's abundant blue resources into a powerful engine for health, prosperity, and resilience.

CONFLICT OF INTEREST

The author declares no conflicts of interest, and I confirm that no AI tools were used in the generation or composition of this work.

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Influence of Axillary Bud Types on the Branching Angle of New Shoots and the Growth Quality of Bud Sticks in Rubber Tree 'Reken 628'

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Abstract*—To investigate how axillary bud type regulates shoot branching angle and bud stick quality in rubber trees, this study used 'Reken 628' budded seedlings (rootstock: GT1). Decapitation was performed during the top leaf whorl sprouting stage at two positions: between the second and top whorls, and 1 cm below the lowest leaf of the second whorl, creating petiole bud and scale bud treatments. Phenological development and morphological indices—plant height, stem diameter, branching angle, leaf dimensions, N content, and surface temperature—were measured through three leaf whorl stages. At the first whorl, scale buds produced significantly wider leaves at the small bronze and color-changing stages, with longer phenological duration, while petiole buds had larger branching angles. By the second whorl, scale bud shoots showed superior plant height, stem diameter, leaf size, and surface temperature, but lower leaf N and larger branching angles. At the third whorl, scale bud branching angle was 88.44% higher than petiole buds, and leaf surface temperature was 1.02% higher. Correlation analysis indicated stronger growth synergy in scale buds, while petiole buds showed tighter links between branching angle and leaf traits. In conclusion, axillary bud type influences branching angle and bud stick quality by modulating growth traits and their correlations, offering a theoretical basis for optimizing rubber tree seedling cultivation and plant architecture.

***Keywords*—Hevea brasiliensis; axillary bud type; branching angle; new shoot growth; morphological indices**

I. INTRODUCTION

As a globally important tropical cash crop, *Hevea brasiliensis* produces natural rubber, a vital industrial raw material and strategic resource. In recent years, the persistent slump in natural rubber prices and the decline in economic benefits have weakened the willingness of rubber cultivation entities to expand production. Nevertheless, the natural rubber industry is a pillar agricultural industry in tropical regions of China [1]. The Central Government Document No.1 in 2025 clearly stated the need to promote the stable production and quality improvement of natural rubber, and the document in 2026 further required advancing the steady development of the industry. Rubber tree seedlings are a key factor restricting the production capacity of natural rubber [2]. Intercropping in rubber plantations is an effective approach to address the persistent low rubber prices and the prevalent long-term losses in rubber cultivation. In the cultivation and management of rubber trees, the plant architecture of budded seedlings exerts a decisive influence on the field ventilation and light transmission efficiency, nutrient transport and yield of intercropped crops in rubber plantations. Among them, the branching angle, as a core index for regulating rubber tree plant architecture, is closely related to crown structure and light energy utilization efficiency, and has a profound impact on the growth and development of intercropped crops in rubber plantations. *Hevea brasiliensis* 'Reken 628' features a tall tree body, high branching position, small crown ratio, a more compact and sparse crown structure, a small number of primary branches with narrow branching angles and a high crown roundness, accompanied by an obvious natural self-pruning phenomenon from bottom to top. These characteristics result in a low canopy density of its plantations, making it more suitable for the growth of intercropped crops [3]. A comprehensive evaluation system for the growth quality of its bud sticks is of great guiding significance for the high-quality and efficient cultivation of this cultivar.

At present, the natural rubber industry is faced with numerous challenges in the standardized cultivation of high-quality seedlings and the precise regulation technology of plant architecture, such as low seedling raising efficiency, insufficient seedling uniformity and unsatisfactory branching angles [4-5], which directly affect the production efficiency and management costs of rubber plantations. Mini-seedling budding technology has become the core method for factory seedling raising due to its remarkable advantages [6-7]. By utilizing seed nutrients for early budding when the cotyledons of mini-seedlings are unexpanded, this technology shortens the growth period of rootstocks, realizes the miniaturization of seedlings and shortens the seedling raising cycle. It boasts high seedling raising efficiency, low cost and easy transportation, and the resulting seedlings have a well-developed root system, strong stress resistance and an early tapping age [8-11]. It has been widely applied in rubber cultivation areas of Yunnan and Guangdong Provinces [8-15]. However, its promotion is hindered in producing areas such as Hainan due to the low rubber prices and labor shortage, with the core problems being the low survival rate of budding affected by rootstock seeds, bud stick quality and climate conditions, which leads to seedling waste, increased subsequent tending and management costs, and inconsistent quality of outplanted seedlings. Previous studies have mostly focused on the effects of rootstock seed types(4), survival rate of mini-seedling budding [10,16], sprouting dynamics [17-21], the position of bud pieces on the leaf whorls of bud sticks [22], bud piece types [23]and bud piece sources [24-26] on the post-budding effects. Yet, the intrinsic mechanism by which axillary bud types (scale buds and petiole buds), the core organs for shoot sprouting of budded seedlings, regulate the sprouting rhythm and growth vigor of bud sticks, and thereby affect the formation of branching angles and the growth quality of bud sticks, has not been systematically elucidated. Clarifying the correlations between different axillary bud types and branching angles as well as bud stick growth indices can provide a new theoretical basis and practical approach for the precise bud selection and plant architecture optimization of rubber tree budded seedlings. Existing studies have confirmed that the branching characteristics of plants have a genetic basis, and there are obvious genetic variation characteristics in branching angles among different cultivars [3], which lays a foundation for the research on regulating branching angles through axillary bud types. In addition, the formation of plant branching is a complex biological process, precisely regulated by multiple factors such as genetic factors, hormones, metabolic pathways and environmental conditions [26-36], and exerts a significant impact on plant growth, development and yield [37]. These findings provide a multi-dimensional analytical perspective for this study, and an in-depth understanding of these regulatory mechanisms is crucial for the precise improvement of rubber tree plant architecture.

In view of this, this study innovatively focuses on the differences in axillary bud types of *Hevea brasiliensis* 'Reken 628', constructs two treatments of petiole buds and scale buds through differential topping methods, systematically observes the growth phenological process of the first leaf whorl after topping, and determines the stem and leaf morphological indices of newly sprouted shoots at the stable stages of the first to third leaf whorls (including mother stem, plant height, stem diameter, branching angle, leaf length, leaf width, leaf N content, leaf SPAD value, leaf surface humidity and leaf surface temperature of newly sprouted shoots). The aim is to deeply explore the regulatory effects and potential mechanisms of different axillary bud types on the branching angle of newly sprouted shoots and the growth quality of bud sticks. The results of this study will fill the research gap in this field, provide a new theoretical basis and practical guidance for the precise bud selection and plant architecture optimization of rubber tree budded seedlings, and thus promote the high-quality and efficient development of the natural rubber industry.

II. MATERIAL AND METHODS

Experimental site The experiment was conducted at the Rubber Tree Mini-seedling Budding Demonstration Base of Rubber Research Institute, Chinese Academy of Tropical Agricultural Sciences, Danzhou City, Hainan Province (109°29′E, 19°30′N, with an altitude of 116.9 m). The base has a tropical monsoon climate. During the experiment, the annual average temperature was 21 ~ 30°C, the annual average precipitation was 1652.3 mm, and the annual average sunshine duration was 1734 h, which is suitable for the growth of rubber trees.

Experimental Materials GT1 seeds were sown in sand beds in October 2021, and GT1 seedlings were obtained in November. In December, the GT1 seedlings were transplanted into single-hole inverted conical seedling raising tubes for further cultivation until the root system grew to the bottom holes of the tubes. In May 2022, 135 rootstock tube seedlings with consistent growth were selected and planted in the base, with a plant spacing of 40 cm and a row spacing of 60 cm. Budding was performed on GT1 seedling rootstocks in the middle and late October 2022. The bud sticks were collected from the Improved Rubber Tree Seedling Breeding Base of Rubber Research Institute, Chinese Academy of Tropical Agricultural Sciences, with the cultivar of 'Reken 628'. The bud sticks had 5 leaf whorls when collected, and plump axillary buds between the 3rd and 4th leaf whorls from the top were selected for budding.

The binding was removed in December 2022, and rootstock sawing was conducted in March 2023 to cultivate one-year-old single-stem bud sticks. In September 2023, the bud sticks were sawn for the second time at 15 cm above the budding interface, and only one robust bud stick was retained on each rootstock of each treatment after sawing. In September 2024, the bud sticks were sawn for the third time at 30 cm above the budding interface, and three-year-old single-stem bud sticks of *Hevea brasiliensis* 'Reken 628'-GT1 seedling rootstocks with consistent growth and four-leaf whorls were cultivated. When the top leaf whorl was in the stage of sprouting and elongation with unexpanded leaflets, topping was carried out at the junction of the second leaf whorl from the top and the top leaf whorl, and 1 cm below the first petiolate leaf from the bottom of the second leaf whorl from the top, respectively, to form two treatments of petiole buds and scale buds. Each treatment had 3 replicates with 10 plants per replicate. Unified water and fertilizer management and pest and disease control were adopted during the experiment to ensure consistent environmental conditions.

Experimental Methods In the late July 2025, phenological observations (from axillary bud sprouting after topping to the senescence stage) were carried out on 30 tagged plants with consistent growth in the two experimental treatments. The time nodes of each key phenological stage were recorded, and the phenological duration of one leaf whorl was counted. Plant height, leaf length, leaf width and branching angle (the included angle between newly sprouted shoots and the mother stem, measured at 4 cm above the junction of newly sprouted shoots and the mother stem) were measured at the stages of fully expanded small bronze leaflets, large bronze stage, color-changing stage, light green stage, stable stage and senescence stage, respectively.

From September to December 2025, the morphological indices of the mother stem (mother stem diameter) and newly sprouted shoots, including branching angle, plant height (from the dense node bud of each leaf whorl to the stem apex of the corresponding leaf whorl), stem diameter (measured at the dense node bud of each leaf whorl), leaf length (from the junction of petiole and leaf blade to the leaf tip), leaf width (the widest part in the middle of the leaf blade), leaf SPAD value, leaf N content, leaf surface temperature and leaf relative humidity, were measured from bottom to top at the 1st, 2nd and 3rd leaf whorl positions of the tagged plants in the two experimental treatments, respectively.

The mother stem diameter and the stem diameter of newly sprouted shoots were measured with a vernier caliper with an accuracy of 0.01 mm. The branching angle was determined by measuring the distance of the included angle between newly sprouted shoots and the mother stem with a vernier caliper (0.01 mm accuracy) to analyze the differences in the included angle between newly sprouted shoots from different bud sources and the mother stem. Plant height was measured with a tape measure with an accuracy of 1 mm to compare the plant height differences of shoots sprouted from scale buds and petiole buds. Leaf length and leaf width were measured with a transparent straight ruler (1 mm accuracy); leaf SPAD value, leaf N content, leaf surface temperature and leaf relative humidity was determined with a chlorophyll meter (TYS-N, Beijing Zhongke Weier Technology Development Co., Ltd.).

Data processing and analysis Excel 2021 was used for data collation, data processing system statistical software package (DPS) 20.05 for significance test of differences (Student's t-test), GraphPad Prism 8.3 for mapping, and Origin 2024 for Spearman correlation analysis and corresponding mapping.

III. RESULT AND ANALYSIS

Comparison of the Growth Process of the First Leaf Whorl

After topping (Fig. 1a, 1b), axillary buds sprouted (Fig. 1c, 1d). During the leaf phenological development, at the S4 stage (small bronze stage, Fig. 1e), the leaf width of shoots sprouted from scale buds (mean: 2.1 cm) was significantly 15.81% wider than that from petiole buds (mean: 1.813 cm), with a difference of 0.2867 cm (Fig. 2c). At the S6 stage (color-changing stage, Fig. 1f), the leaf width of shoots from scale buds (mean: 6.521 cm, Fig. 2d) was significantly 11.47% wider than that from petiole buds (mean: 5.85 cm), with a difference of 0.6708 cm.

Fig.1 Comparison of stem and leaf morphology during the phenological growth of bud sticks from two axillary bud types

Note: Fig. 1a represents petiole buds after topping; Fig. 1b represents scale buds after topping; Fig. 1c represents axillary bud sprouting of petiole buds; Fig. 1d represents axillary bud sprouting of scale buds; Fig. 1e represents the small bronze stage; Fig. 1f represents the color-changing stage; Fig. 1g represents the stable stage; Fig. 1h represents the included angle (branching angle) between newly sprouted shoots and the mother stem.

When the top leaf whorl (the 1st leaf whorl) reached the stable stage (Fig. 1g), the included angle (branching angle) between newly sprouted shoots from petiole buds and the mother stem (mean: 3.467 cm, Fig. 1h) was significantly 15.86% larger than that from scale buds (mean: 2.917 cm), with a difference of 0.55 cm (Fig. 2b). Additionally, the phenological duration required for the leaves of newly sprouted shoots from scale buds to develop into a complete leaf whorl (mean: 45 days) was significantly 23.29% longer than that from petiole buds (mean: 36.5 days), with a difference of 8.5 days (Fig. 2a).

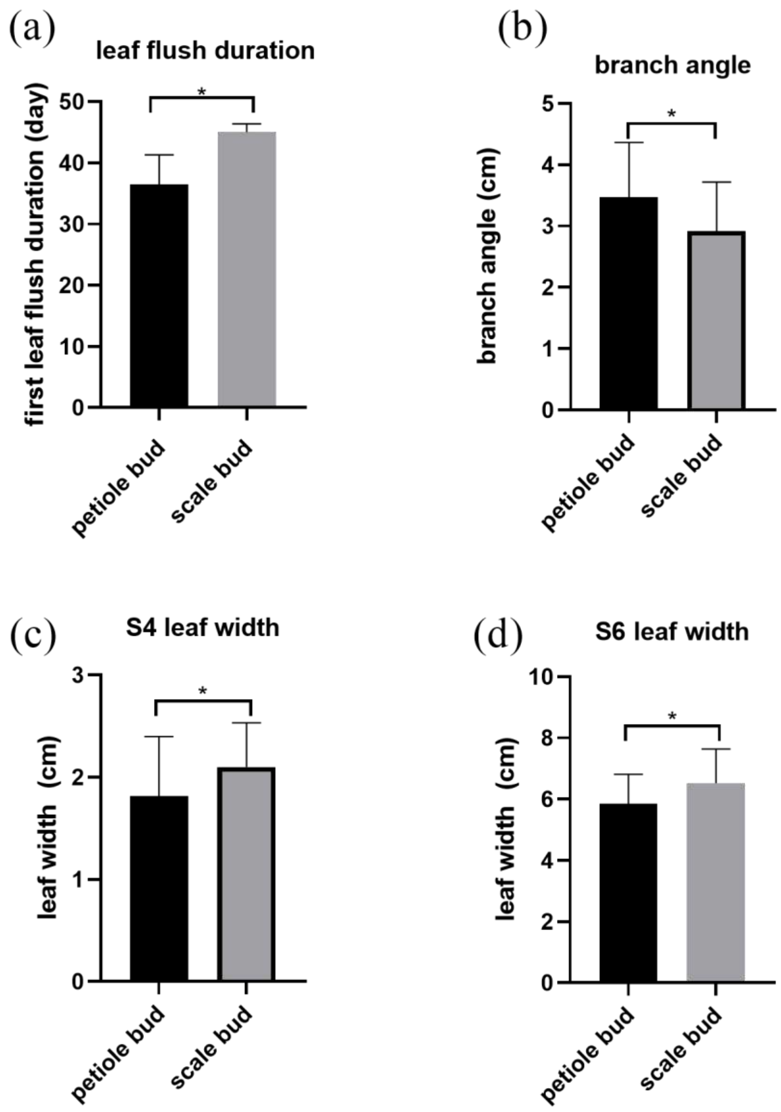

Fig.2 Comparison of stem and leaf morphology during the growth of the first leaf whorl of bud sticks from two axillary bud types

Note: * in the figure indicates a significant difference between treatments at the $p < 0.05$ level, and error bars represent the standard deviation. S4, small bronze stage. S6, color-changing stage.

Comparison of Stem and Leaf Morphology at the Stable Stage of the First Leaf Whorl

When the bud sticks grew to the stable stage of the first leaf whorl, the plant height of newly sprouted shoots from petiole buds (Fig. 3a, mean: 39.08 cm) was significantly lower by approximately 25.69% than that from scale buds (mean: 49.13 cm), with a difference of 10.04 cm. The stem diameter of shoots from scale buds (Fig. 3b, mean: 8.737 mm) was significantly 17.79% thicker than that from petiole buds (mean: 7.418 mm), with a difference of 1.32 mm. The leaf length of shoots from scale buds (Fig. 3c, mean: 16.64 cm) was significantly 17.52% longer than that from petiole buds (mean: 14.16 cm), with a difference of 2.481 cm. The leaf width of shoots from scale buds (Fig. 3d, mean: 6.939 cm) was significantly 20.47% wider than that from petiole buds (mean: 5.76 cm), with a difference of 1.179 cm.

In contrast, the leaf N content of shoots from scale buds (Fig. 3e, mean: 16.76 mg/g) was significantly 4.86% lower than that from petiole buds (mean: 17.61 mg/g), with a difference of 0.8556 mg/g. The leaf surface temperature of shoots from scale buds (Fig. 3f, mean: 31.02 ℃) was significantly 3.66% higher than that from petiole buds (mean: 29.92 °C), with a difference of 1.096°C.

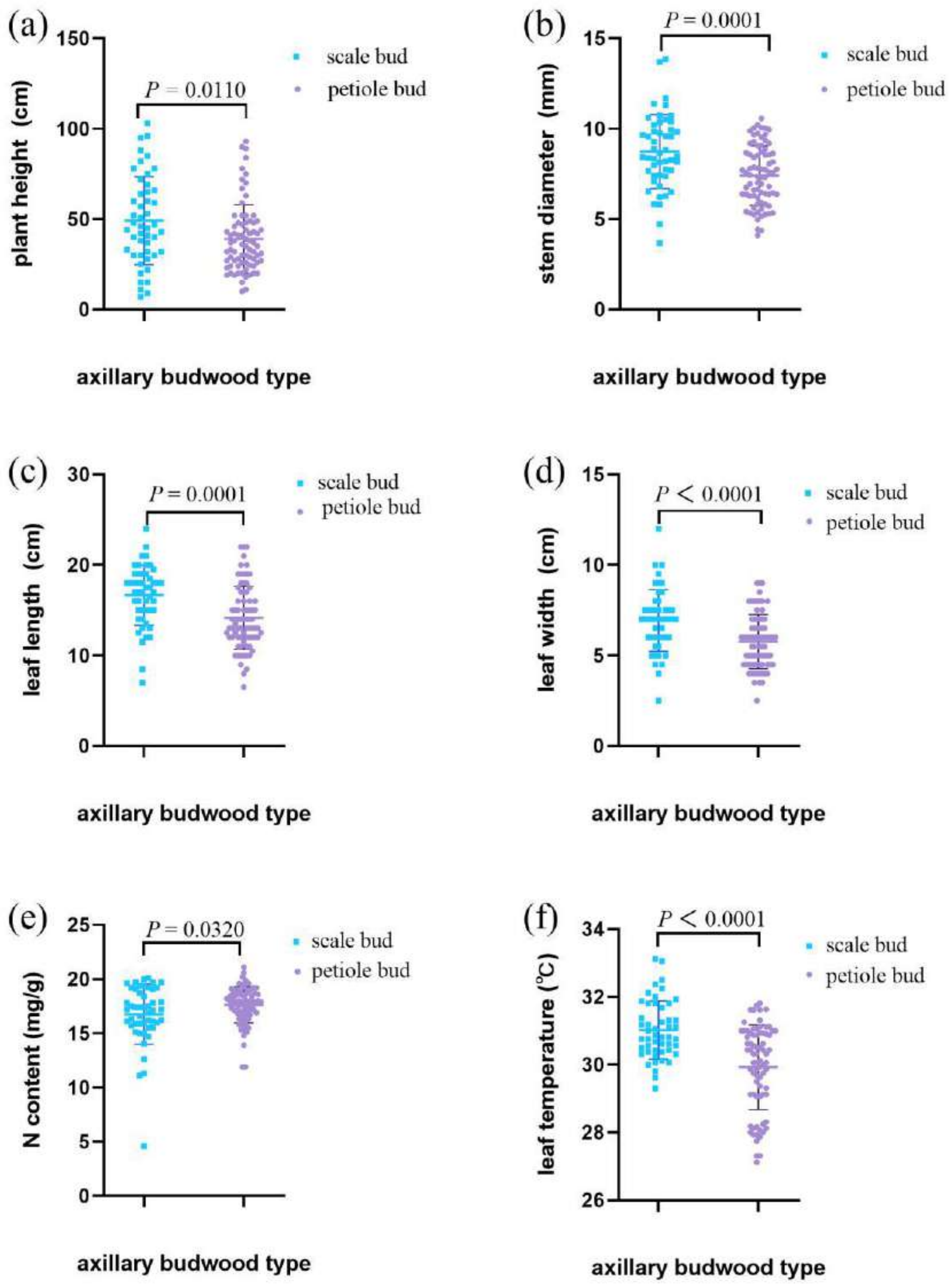

Fig.3 Comparison of stem and leaf morphological traits of bud sticks at the first leaf whorl stage between two axillary bud types

Note: p-values in the figure indicate significant differences between treatments at the 0.05 level ($p < 0.05$) and highly significant differences at the 0.01 level ($p < 0.01$). Error bars represent the standard deviation.

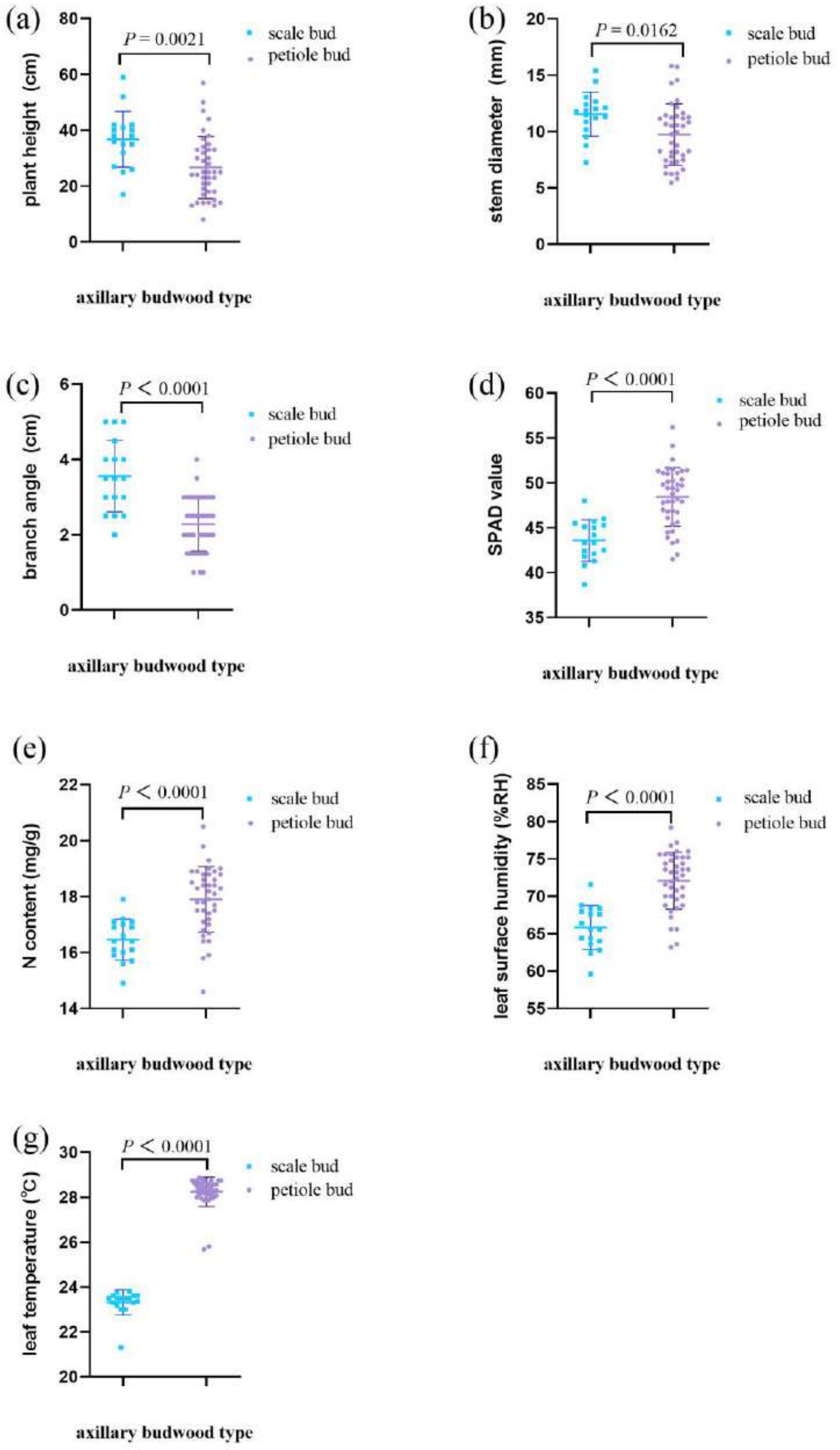

Fig.4 Comparison of stem and leaf morphological traits of bud sticks at the second leaf whorl stage between two axillary bud types

Note: p-values in the figure indicate significant differences ($p < 0.05$) and highly significant differences ($p < 0.01$) between treatments. Error bars represent the standard deviation.

Comparison of Stem and Leaf Morphology at the Stable Stage of the Second Leaf Whorl

When the bud sticks developed to the stable stage of the second leaf whorl, the plant height of newly sprouted shoots from petiole buds (Fig. 4a, mean: 26.65 cm) was extremely significantly lower by approximately 27.50% than that from scale buds (mean: 36.76 cm), with a difference of 10.11 cm. The stem diameter of shoots from scale buds (Fig. 4b, mean: 11.54 mm) was significantly 18.60% thicker than that from petiole buds (mean: 9.732 mm), with a difference of 1.811 mm. The branching angle of shoots from scale buds (Fig. 4c, mean: 3.559 cm) was extremely significantly 55.55% larger than that from petiole buds (mean: 2.288 cm), with a difference of 1.271 cm. The chlorophyll SPAD value of shoots from scale buds (Fig. 4d, mean: 43.59) was extremely significantly lower by approximately 9.99% than that from petiole buds (mean: 48.44), with a difference of 4.849. The leaf N content of shoots from scale buds (Fig. 4e, mean: 16.46 mg/g) was extremely significantly lower by approximately 8.04% than that from petiole buds (mean: 17.90 mg/g), with a difference of 1.444 mg/g. The leaf surface humidity of shoots from scale buds (Fig. 4f, mean: 65.84%) was extremely significantly lower by approximately 8.67% than that from petiole buds (mean: 72.08%), with a difference of 6.245 percentage points. The leaf surface temperature of shoots from scale buds (Fig. 4g, mean: 23.32 ℃) was extremely significantly lower by approximately 17.42% than that from petiole buds (mean: 28.24℃), with a difference of 4.922℃.

Comparison of Stem and Leaf Morphology at the Stable Stage of the Third Leaf Whorl

When the bud sticks grew to the stable stage of the third leaf whorl, the branching angle of newly sprouted shoots from scale buds (Fig. 5a, mean: 3.455 cm) was extremely significantly 88.49% larger than that from petiole buds (mean: 1.833 cm), with a difference of 1.621 cm. The leaf surface temperature of shoots from scale buds (Fig. 5b, mean: 21.99 ℃) was extremely significantly 1.02% higher than that from petiole buds (mean: 21.77 ℃), with a difference of 0.2227 ℃. No significant differences were observed in the indices of mother stem, plant height, stem diameter, leaf length, leaf width, SPAD value, leaf N content and leaf surface humidity between the two treatments.

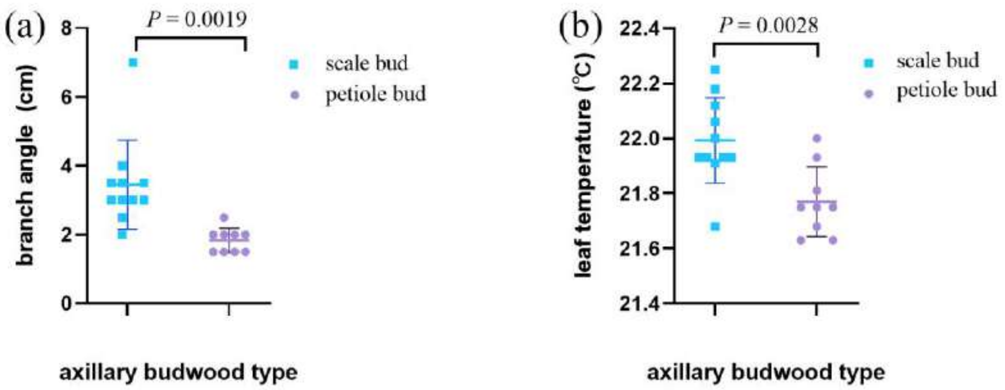

Fig.5 Comparison of stem and leaf morphological traits of bud sticks at the third leaf whorl stage between two axillary bud types

Note: *p*-values in the figure indicate significant differences ($p < 0.05$) and highly significant differences ($p < 0.01$) between treatments. Error bars represent the standard deviation.

Correlation analysis

Figure 6 presents the correlations among various stem and leaf morphological indices of newly sprouted shoots from the two axillary bud types (scale buds and petiole buds) of *Hevea brasiliensis* 'Reken 628' at the first, second and third leaf whorl stages.

At the stable stage of the first leaf whorl for shoots from scale buds (Fig. 6A), the mother stem was extremely significantly positively correlated with the plant height and stem diameter of the newly sprouted shoots, and significantly positively correlated with the leaf width, SPAD value and leaf surface temperature of the shoots; the plant height of the shoots was extremely significantly positively correlated with their stem diameter and leaf width, very significantly positively correlated with their leaf length and leaf surface temperature, and significantly positively correlated with their SPAD value and leaf N content; the stem diameter of the shoots was extremely significantly positively correlated with their leaf length and leaf width, and significantly positively correlated with their leaf N content; the branching angle of the shoots was very significantly positively correlated with leaf surface temperature; the leaf length of the shoots was extremely significantly positively correlated with their leaf width, very significantly positively correlated with their leaf N content, and significantly positively correlated with their SPAD value and leaf surface humidity, respectively; the leaf width of the shoots was extremely significantly positively correlated with their SPAD value, leaf N content and leaf surface humidity, respectively; the SPAD value of the shoots was extremely significantly positively correlated with their leaf N content and leaf surface humidity; the leaf N content of the shoots was extremely significantly positively correlated with their leaf surface humidity.

At the stable stage of the second leaf whorl for shoots from scale buds (Fig. 6B), the plant height of the newly sprouted shoots was significantly positively correlated with their SPAD value, leaf N content and leaf surface humidity, respectively; the stem diameter of the shoots was significantly positively correlated with their leaf width; the branching angle of the shoots was very significantly negatively correlated with their leaf length, significantly negatively correlated with their leaf width, and significantly positively correlated with leaf surface temperature; the leaf length of the shoots was extremely significantly positively correlated with their leaf width; the SPAD value of the shoots was extremely significantly positively correlated with their leaf N content and leaf surface humidity, respectively; the leaf N content of the shoots was extremely significantly positively correlated with their leaf surface humidity.

At the stable stage of the third leaf whorl for shoots from scale buds (Fig. 6C), the mother stem was very significantly positively correlated with the plant height of the newly sprouted shoots; the plant height of the shoots was very significantly positively correlated with their stem diameter and significantly positively correlated with their leaf width; the stem diameter of the shoots was significantly positively correlated with their leaf length and very significantly positively correlated with their leaf width; the leaf length of the shoots was extremely significantly positively correlated with their leaf width; the SPAD value of the shoots was extremely significantly positively correlated with their leaf N content and leaf surface humidity; the leaf N content of the shoots was extremely significantly positively correlated with their leaf surface humidity.

At the stable stage of the first leaf whorl for shoots from petiole buds (Fig. 6D), the mother stem was extremely significantly positively correlated with the plant height and stem diameter of the newly sprouted shoots, and significantly positively correlated with the branching angle of the shoots; the plant height of the shoots was extremely significantly positively correlated with their stem diameter, leaf length and leaf width, and significantly positively correlated with their branching angle, SPAD value, leaf N content, leaf surface humidity and leaf surface temperature; the stem diameter of the shoots was extremely significantly positively correlated with their leaf length and leaf width, and significantly positively correlated with their SPAD value, leaf N content and leaf surface humidity, respectively; the branching angle of the shoots was significantly positively correlated with their leaf width; the leaf length of the shoots was extremely significantly positively correlated with their leaf width and SPAD value, very significantly positively correlated with their leaf N content and leaf surface humidity, and significantly positively correlated with their leaf surface temperature; the leaf width of the shoots was very significantly positively correlated with their SPAD value, leaf N content and leaf surface humidity; the SPAD value of the shoots was extremely significantly positively correlated with their leaf N content, leaf surface humidity and leaf surface temperature; the leaf N content of the shoots was extremely significantly positively correlated with their leaf surface humidity and leaf surface temperature; the leaf surface humidity of the shoots was extremely significantly positively correlated with their leaf surface temperature.

At the stable stage of the second leaf whorl for shoots from petiole buds (Fig. 6E), the mother stem was significantly positively correlated with the stem diameter and branching angle of the newly sprouted shoots, and significantly negatively correlated with the SPAD value and leaf N content of the shoots; the plant height of the shoots was extremely significantly positively correlated with their stem diameter and leaf length, and very significantly positively correlated with their leaf width; the stem diameter of the shoots was extremely significantly positively correlated with their leaf length and leaf width; the leaf length of the shoots was extremely significantly positively correlated with their leaf width; the SPAD value of the shoots was extremely significantly positively correlated with their leaf N content and leaf surface humidity; the leaf N content of the shoots was extremely significantly positively correlated with their leaf surface humidity.

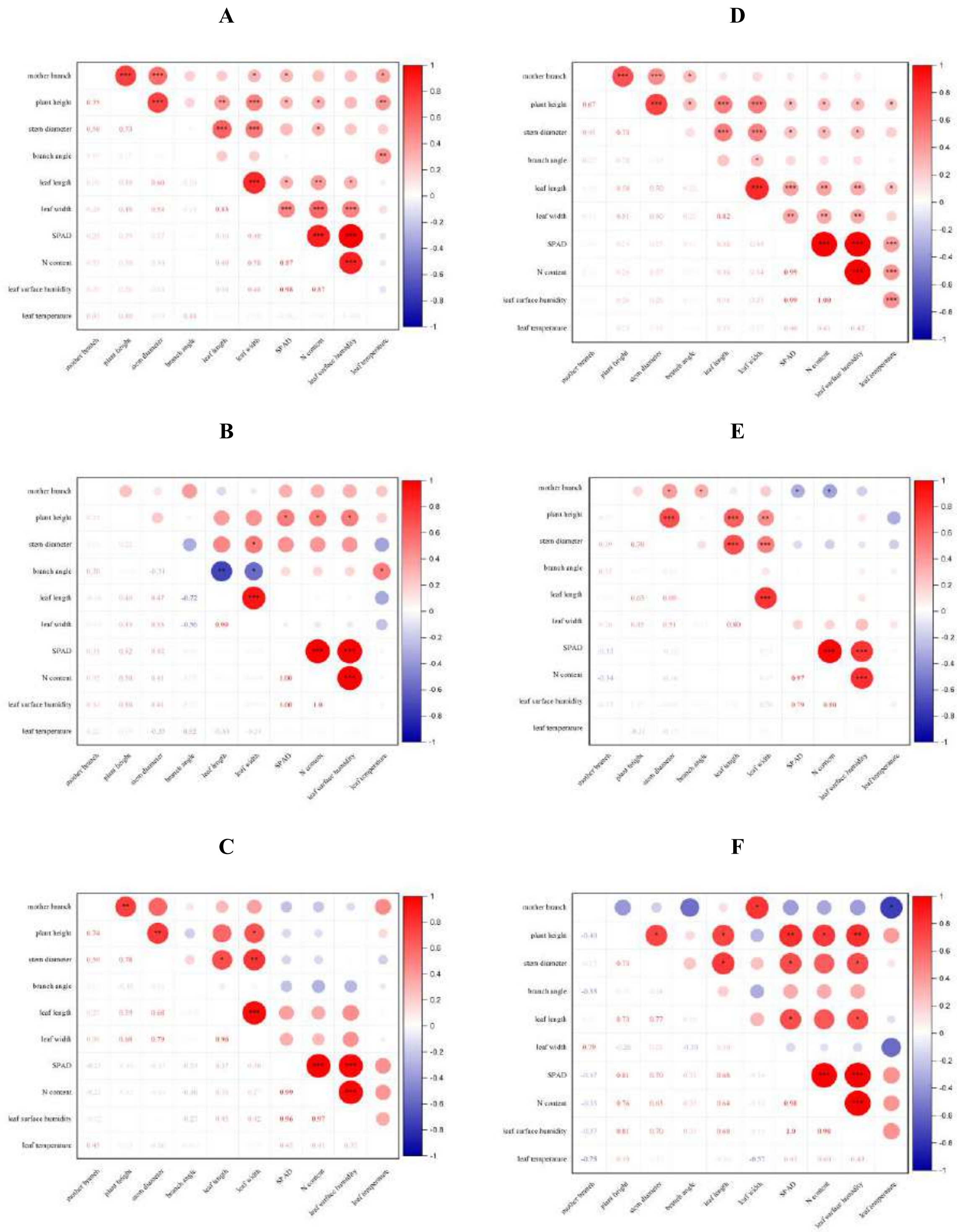

Fig.6 Correlation analysis of stem and leaf morphological indices of newly sprouted shoots from two axillary bud types

Note: Panels A–C represent the correlation analysis of stem and leaf morphological indices of newly sprouted shoots from scale buds at the first, second and third leaf whorl stages, respectively; Panels D–F represent the correlation analysis of stem and leaf morphological indices of newly sprouted shoots from petiole buds at the first, second and third leaf whorl stages, respectively. The size of the circles and the depth of the color represent the magnitude of correlation coefficients and the level of significance, with blue indicating negative correlation and red indicating positive correlation. The upper triangle shows the significance markers of correlations, where *, ** and *** indicate statistically significant (p<0.05), very significant (p<0.01) and extremely significant (p<0.001) correlation coefficients, respectively. The lower triangle shows the values of correlation coefficients, where |r|≥0.7 indicates a strong correlation, 0.3≤|r|<0.7 indicates a moderate correlation, and |r|<0.3 indicates a weak correlation.

At the stable stage of the third leaf whorl for shoots from petiole buds (Fig. 6F), the mother stem was significantly positively correlated with the leaf width of the newly sprouted shoots and significantly negatively correlated with their leaf surface temperature; the plant height of the shoots was significantly positively correlated with their stem diameter, leaf length and leaf N content, respectively, and very significantly positively correlated with their SPAD value and leaf surface humidity; the stem diameter of the shoots was significantly positively correlated with their leaf length, SPAD value and leaf surface humidity, respectively; the leaf length of the shoots was significantly positively correlated with their SPAD value and leaf surface humidity; the SPAD value of the shoots was extremely significantly positively correlated with their leaf N content and leaf surface humidity; the leaf N content of the shoots was extremely significantly positively correlated with their leaf surface humidity.

Comprehensive analysis

Using branching angle as a lower-is-better indicator, combined with mother stem, plant height, stem diameter, leaf length, leaf width, SPAD value, leaf N content, leaf surface humidity and leaf surface temperature of newly sprouted shoots, the TOPSIS method was used to conduct a multi-index comprehensive evaluation on the overall performance of newly sprouted shoots from two axillary bud types at different leaf whorl stages. The results are shown in Table 1. According to the comprehensive index and ranking, newly sprouted shoots from petiole buds at the third leaf whorl had the highest comprehensive index (0.5176), ranking first; followed by shoots from petiole buds at the first leaf whorl (0.5068), ranking second. Shoots from scale buds at the third leaf whorl (0.4793) and at the first leaf whorl (0.4661) ranked third and fourth, respectively. Both types of newly sprouted shoots showed relatively poor comprehensive performance at the second leaf whorl stage: shoots from petiole buds at the second leaf whorl had a comprehensive index of 0.4091, ranking fifth, and shoots from scale buds at the second leaf whorl had the lowest comprehensive index (0.4047), ranking sixth. Overall, the comprehensive performance of newly sprouted shoots from petiole buds showed a gradually increasing trend with growth process, while shoots from scale buds showed a growth trough at the second leaf whorl stage, with relatively unstable comprehensive performance.

Table 1 Comprehensive Evaluation of Newly Sprouted Shoots Using the TOPSIS Method Based on Stem and Leaf Morphological Indices

Leaf whorl - bud type	Statistic CI	Rank
3rd-leaf whorl (petiole buds)	0.5176	1
1st-leaf whorl (petiole buds)	0.5068	2
3rd-leaf whorl (scale buds)	0.4793	3
1st-leaf whorl (scale buds)	0.4661	4
2nd-leaf whorl (petiole buds)	0.4091	5
2nd-leaf whorl (scale buds)	0.4047	6

Note: CI, approximation to the Optimal Vectors.

IV. DISCUSSION AND CONCLUSION

DISCUSSION

In this study, two axillary bud types of *Hevea brasiliensis* 'Reken 628', namely petiole buds and scale buds, were successfully induced by differentiated decapitation treatments, and their regulatory effects on the branching angle and growth quality of newly sprouted shoots were systematically investigated. The results clearly demonstrated significant differences in phenological progression, morphological and physiological indices, and correlation patterns between the two axillary bud types. The fundamental reason for these differences lies in the inherent distinctions in the occurrence position and developmental basis of axillary buds. Scale buds developed more sufficiently and accumulated more abundant nutrients, whereas petiole buds germinated faster but had a relatively weak growth foundation. This study is the first to systematically compare the effects of these two axillary bud types on shoot growth, branching angle and phenological progression in rubber trees, filling the research gap in this field.

The present study found that axillary bud type significantly shaped the growth pattern of rubber tree shoots. Shoots derived from scale buds exhibited a robust growth strategy. In terms of phenological progression, scale buds had a longer leaf whorl development cycle, which provided sufficient time for full leaf expansion and establishment of photosynthetic capacity. At the first leaf whorl stage, scale buds showed significantly greater leaf width than petiole buds, indicating an advantage in early photosynthetic potential. During the stable periods of the first and second leaf whorls, scale buds consistently exhibited significant advantages in key vegetative growth indices such as plant height, stem diameter, leaf length and leaf width. This was attributed to their sufficient nutrient reserves and more efficient nitrogen utilization, allowing nutrients to be more effectively converted into biomass accumulation. Such a stable growth pattern enabled scale-bud shoots to form thicker stems and larger leaf areas, laying a solid foundation for subsequent growth.

In contrast, shoots from petiole buds displayed a fast-germinating growth pattern. They had a relatively shorter leaf whorl phenological period, indicating faster germination and growth. At the first leaf whorl stage, the branching angle of petiole-bud shoots was significantly larger than that of scale-bud shoots, which might be related to their insertion position and germination direction, leading to an outward growth tendency in the early stage. Although petiole buds were slightly inferior to scale buds in vegetative growth indices at the initial stage, their fast-germinating characteristic allowed them to quickly occupy space, which could be advantageous under certain cultivation objectives.

As a core index regulating rubber tree plant architecture [3, 39–40], branching angle was dynamically regulated by axillary bud type, and such regulation showed obvious stage-specific characteristics. At the first leaf whorl stage, petiole-bud shoots had a significantly larger branching angle than scale-bud shoots, reflecting their early outward growth tendency. However, with further shoot development, at the second and third leaf whorl stages, the branching angle of scale-bud shoots became significantly larger instead. This shift revealed that rubber tree plant architecture is not static but possesses dynamic regulatory ability. The rapid germination of petiole buds might lead to a larger branching angle in the early stage, while the vegetative growth advantage of scale buds may enable them to form a larger branching angle in the later stage to adapt to their stronger growth vigor and leaf expansion. Such stage-specific differences suggest that flexible regulation strategies should be adopted in cultivation management according to different growth stages and target plant architectures.

Correlation analysis further revealed differences in the coordination of growth indices between the two axillary bud types. Shoots from scale buds showed stronger synergy among growth indices, with closer coordinated growth relationships among various vegetative organs, which complemented their "robust" growth pattern. In contrast, the branching angle of shoots from petiole buds was more closely correlated with leaf indices, which may reflect a specific balancing mechanism between branching angle formation and leaf development during rapid germination [38].

The TOPSIS comprehensive evaluation results provided a more comprehensive perspective. Petiole bud shoots at the third leaf whorl stage showed the best overall performance, confirming their characteristic of "fast germination followed by steady growth". Although not dominant in the early stage, their comprehensive performance continuously improved with growth. In contrast, scale bud shoots at the second leaf whorl stage showed the poorest overall performance, which may be related to the critical period of nutrient distribution at this stage, during which a large amount of nutrients was preferentially allocated to leaf and stem construction, leading to a temporary decline in some comprehensive evaluation indices. Such stage-specific differences in overall performance provide an important basis for formulating refined cultivation and management measures.

The results of this study provide a theoretical basis and practical guidance for precise bud selection and plant architecture optimization of rubber tree budded seedlings. With their "robust" growth pattern, scale bud shoots exhibited excellent vegetative growth indices and stronger index coordination at all leaf whorl stages, making them suitable for cultivating high-quality, robust and uniform budded seedlings. In contrast, petiole bud shoots, with their "fast-germinating" growth pattern, had a larger branching angle in the early stage and a prominent correlation between branching angle and leaf or stem indices, making them more suitable for optimizing rubber tree plant architecture to improve field ventilation and light transmission efficiency.

Therefore, in production practice, axillary bud types should be selectively chosen according to specific cultivation objectives. Scale buds are preferred for overall robustness and uniformity of seedlings, while petiole buds can be considered if the focus is on optimizing plant architecture by adjusting branching angle. Meanwhile, combined with the growth characteristics of different axillary bud types, implementing differentiated cultivation and management measures — such as strengthening nutrient management during the growth trough of scale buds, or regulating the branching angle of petiole buds via pruning and branch pulling — will significantly improve the breeding efficiency and seedling quality of rubber tree budded seedlings, thereby providing strong technical support for quality improvement and efficiency enhancement of the natural rubber industry.

CONCLUSION

Through an in-depth investigation of axillary bud types (scale buds and petiole buds) in *Hevea brasiliensis* 'Reken 628', this study systematically clarified their key roles in regulating the branching angle and growth quality of newly sprouted shoots, and revealed significant differences in phenological progression, morphological and physiological indices, and overall performance between the two bud types. These findings not only fill the research gap in this field but also provide a solid theoretical basis for high-quality breeding and plant architecture optimization of rubber tree budded seedlings.

Specifically, scale buds exhibited a robust growth pattern, characterized by a longer leaf whorl phenological period. At multiple growth stages, their vegetative growth indices including plant height, stem diameter, leaf length, and leaf width were significantly superior to those of petiole-bud shoots, and their growth indices showed stronger synergy. Scale buds had higher nitrogen use efficiency and more effective biomass accumulation, making them an ideal choice for cultivating robust and uniform high-quality seedlings.

In contrast, petiole buds displayed a fast-germinating growth pattern, with a relatively shorter phenological period, rapid early germination, and a significantly larger branching angle at the first leaf whorl stage. Although slightly inferior in early vegetative growth, the TOPSIS comprehensive evaluation showed that the overall performance of petiole-bud shoots gradually optimized with growth, especially reaching the optimum at the third leaf whorl stage. This indicated their late steady growth characteristic, endowing them with unique potential in optimizing plant architecture and improving field ventilation and light transmission efficiency.

The results of this study have important practical guiding significance for the natural rubber industry. In production, a precise bud selection strategy can be implemented according to specific seedling breeding objectives: scale buds should be prioritized for cultivating robust and uniform high-quality seedlings, while petiole buds are preferred for optimizing plant architecture and effectively regulating branching angle to improve field ventilation and light transmission. Meanwhile, combined with the growth characteristics of different axillary bud types, formulating and implementing differentiated cultivation management measures — such as strengthening nutrient management during the growth trough of scale buds, or regulating the branching angle of petiole buds via pruning and branch pulling — can significantly improve the breeding efficiency and seedling quality of rubber tree budded seedlings, thus strongly promoting the quality improvement, efficiency enhancement, and sustainable development of the natural rubber industry.

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Efficacy Evaluation of Eight Bio-Pesticides and two Synthetic Pesticides in the Control of Cowpea Weevils (*Callosobruchus maculatus)* and Mold in Sokoto State, Northwest Nigeria

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***Abstract*— *Two laboratory experiments to evaluate the efficacy of eight bio-pesticides (Plant derivatives) and two synthetic pesticides in mitigating post-harvest losses caused by cowpea bruchids (Callosobruchus maculatus) and storage mold were carried out in Illela, Sokoto state, Northwest Nigeria. The research used a completely Randomized Design (CRD) experiments with ten (10) treatments replicated four (4) times. The efficacy of each treatment was evaluated against egg oviposition, seed perforation, weight loss and mold infestation levels across both restricted and unrestricted weevil attack. The result of the experiment showed significant treatments effect across all parameters taken ($P \leq 0.05$). Phostoxin significantly demonstrated absolute potency under restricted condition, achieving complete inhibition of egg oviposition (0.00 egg). However, under unrestricted infestation condition, the absolute potency of phostoxin in inhibiting egg oviposition observed under restricted infestation was broken as up to 483.00 eggs were laid, but still maintain absolute potency in inhibiting seed perforation (0.00 holes) as the eggs failed to hatch. A combination of mancozeb 80%WP and Acetamprid 40% proved dual significant control against bruchid and fungal infestation throughout the storage period. Regarding bio-pesticides, turmeric proved significantly superior in reducing egg oviposition by 84.53% (152.45 as against 986.01 in the control and also reducing seed perforation by 76.90% (14.81 as against 64.00 exit holes). Again, grape peel powder also exhibited significant deterrent effect by reducing egg oviposition by 83.77% (160.03 as against 986.01 eggs in the control) and in seed perforation by 73.05%. Regarding storage mold infestation, Alligator pepper recorded significantly higher antifungal potency than other bio-pesticides achieving near total mold suppression (1.00 infested seed).*

***Keywords*— Cowpea (Vigna unguiculata), Bruchids (Callosobruchus maculatus), Bio-pesticides, synthetic pesticides, mold.**

I. INTRODUCTION

Cowpea (*Vigna unguiculata)* is one of the most versatile and important legume crops cultivated widely across various regions of the world, particularly in tropical and subtropical climates. It is a major vegetable source of protein for human consumption especially in Africa (Ileke *et al. 2013*). Cowpea is a staple component of the diet in several developing countries and a major source of protein to combat malnutrition in young children in view of expensive animal protein. Cowpea seeds contain about 25% protein, making it extremely valuable in area where many people cannot afford proteinous food such as meat and fish (Lephale *et al.* 2001*)*.

It has been regarded as poor man's meat (Ileke *et al.* 2012. It is an extremely important protein source to vegetarians and people who cannot afford animal protein (Adeyemi *et al*. 2012). Cowpea seeds are also a rich source of minerals and vitamins (Hall *et al.* 2003). The green and dry haulum are feed to livestock particularly in dry season when animal feed is scarce (Ababe et al. 2005) and also as source of income when sold to farmers who use them as livestock feed (Dugje et al. 2009).

Cowpea is a warm weather crop that is well adapted to dryer regions of the tropics like Nigeria where other food legumes do not thrive well. Cowpea, a herbaceous annual plant exhibits a variable growth habit, which can be categorized into erect, semi-erect, prostrate and climbing forms (Ehler and Hall, 1997).

This variability allows it to be cultivated under divert farming systems, from traditional small-scale farms to more intensive large scale agricultural practices. In terms of its morphology, cowpea typically exhibit trifoliate leaves, which are broad and green, enhancing its photosynthetic efficiency. This efficiency helps the plant endure and thrive in harsh environmental conditions, such as extreme heat and limited moisture availability.

Nigeria is the largest producer and consumer, accounting for about 45% of the world's production (Lowenberg – Deboer and Ibro 2008, Ndong *et al. 2012)* while Africa accounts for 75%. Despite the numerous benefits of cowpea, its production and storage face significant challenges.

The production of this crop in Nigeria is low and has not matched the demand of the consumers (Okelede and Ariyo 2000). Among the pulses, cowpea, Banbara groundnut and pigeon pea are the most common and important legume crops in the world (Mahdi and Rahman 2008. Pulses suffer a great damage during storage due to insect attack. The extent of damage by *Callosobruchus maculatus* to pulse seeds is very high both qualitatively and quantitatively (Atwal 2006). *Callosobruchus maculatus* alone accounts for over 90% of damage done to stored cowpea seeds by insect (Caswell 2001). Therefore, an option that can produce satisfactory result in an acceptable and feasible manner to farmers is necessary to achieve the desired goal. The use of plants and minerals as traditional protectants of stored products is an old practice used all over the world. Some of these knowledge have been neglected over past decades. However, there is an increasing interest and necessity to revisit such knowledge. In Nigerian traditional grain storage, *Afrimonium melegueta* seed, *capsicum nigrum* seed, *Allium Sativum, Zingiber Officinale* rhizome, *Azadirachta indica* leaves and *ocimum gratissimum (*scent leaf, are often employed singly or in combination as seed/grain protectant with different but encouraging results, which lead to the objective of this research to evaluate the efficacy of eight bio-pesticides and two synthetic pesticides in the control of cowpea burchid (*Callosobruchus maculatus)* (L) Walp) and mold in Illela, Sokoto state, Northwest Nigerian.

II. MATERIALS AND METHOD

EXPERIMENTAL SITE

The two (2) experiments were conducted at Illela, located in Sokoto state, Northwest Nigeria. The area lies within the semi-arid region of the country and experiences long dry season with high temperature ranging between 35^{oc} and $45^{oc}$and short eratic rain periods. These climatic conditions make cowpea storage highly susceptible to insect and Fungal infestations, particularly the cowpea weevil (*Callosobruchus maculatus* and mold growth.

EXPERIMENTAL DESIGN

The research comprised two experiments, each conducted under a controlled laboratory condition, using a complete randomized Design (CRD), with ten (10) treatments replicated four (4) times.

EXPERIMENTAL MATERIALS

Experimental materials used were

- Cowpea (*Vigna unguiculata)* seeds obtained from an accredited agro-input store in Illela Sokoto state metropolis to ensure purity and uniformity
- Young adults of cowpea bruclids (*Callosobruchus maculatus*) obtained from two (2) months multiplication culture in 10Kg cowpea seeds in non-air tight container.
- Eight plant-based bio-pesticides such as; Wood ash, Grape peel (*vitis vinifera)* powder, Ginger (*zingiber officinale)* rhizome powder, moringa (*moringa oleifera)* leaf powder, scent leaf (*ocinum gratissimum*) powder Alligator pepper (*Aframomum meleguata)* powder, Jatropha curcas (Physic nut) leaf powder and Turmeric (*curcuma longa)* rhizome powder.
- Two (2) synthetic pesticides such as phostoxin (fumigant) and mancozeb 80% WP+ Acetamprid 40% (fungicide plus insecticide) obtained from an accredited agro-input store in Illela, Sokoto state metropolis.
- A wooden storage cage with four (4) partitions. The cage measured 120cm (height) x60cm (width)x 40cm (depth), netted with a wooden door in each partition making a total of four (4) doors for adequate ventilation and easy observation.
- **Production of bio-pesticides**
  The plant materials (Grape peel, Ginger, moringa, scent leaf, Alligator pepper, Turmeric and *Jatropha curcas* were sundried until crisp, and

ground separately into fine powders with a clean mechanical grinder. These were used immediately to avoid caking.

- Wood ash was collected from burnt woods from a charcoal kitchen.

DATA COLLECTION (Experiment 1)

Data were collected on:

- Number of eggs laid by weevils during restricted infestation/attack
- Number of eggs laid by weevils during unrestricted infestation/attack.
- Number of holes created by weevils during restricted infestation/attack
- Number of exit holes created by weevils during unrestricted infestation/attack
- Loss in grain weight due to attack by weevils obtained by subtracting the weight after the attack from the initial weight before the attack.

Experiment 2

- Number of eggs laid by weevils 14 DAI and 28 DAI
- Number of exit holes created by weevils 14DAI and 28DAI.
- Mold incidence 28DAI.

Statistical analysis:

The data collected were analyzed using the genstate release (2012) and analysis of variance outlined by Obi (2001). Separation of treatment means for significant effect was done using fisher's least significance deference (F-LSD) Method.

III. RESULTS

Effect of the pesticides on the mean number of eggs laid during restricted and unrestricted attacks.

The result of the experiment showed significant pesticides treatment effect (P≤ 0.05) on the mean number of eggs laid by the cowpea weevil during restricted attack. The control recorded the highest mean number of 986.01 eggs followed by moringa, alligator pepper and ginger with mean number of 503.00, 492.50 and 455.50 eggs respectively whereas phostoxin recorded the lowest mean of 0.00 egg followed by turmeric with a mean of 152.45 eggs. However, during unrestricted attack, a mean number of 483.00 eggs were laid on samples treated with phostoxin which was also the lowest among all the treatment means. This indicated that phostoxin being a fumigant performs better in an enclosure than in open situation.

Table 1. Effect of the pesticides on the mean number of eggs laid on the grains by the cowpea weevils during restricted and unrestricted attacks.

Treatments	Restricted	Unrestricted
Control	986.01	1910.00
Wood ash	312.02	1529.00
Grape peel powder	160.03	875.00
Ginger rhizome power	455.50	623.00
Moringa leaf powder	503.00	1035.00
Scent leaf powder	372.50	880.00
Alligator pepper fruit powder	492.50	615.00
Phostoxin (synthetic fumigant)	0.00	483.00
Jatropha curcas leaf powder	353.50	644.00
Turmeric rhizome powder	152.45	741.00
F – LSD $_{(0.05)}$	259.80	335.80

Effect of the pesticides on the mean number of exit holes created on the grains by cowpea weevils during restricted and unrestricted attacks.

Statistical analysis of the experiment showed significant treatments effect (P≤ 0.05) on the mean number of exit holes created on the grains by the cowpea weevils during restricted and unrestricted attacks. During restricted attacks, the control recorded the highest mean exit holes of 64.00, while phostoxin recorded the least mean value of 0.00 exit hole followed by turmeric, grape peels and jatropha with mean values of 14.81, 17.25 and 22.85 exit holes respectively. On the other hand, during unrestricted attacks, control also recorded the highest mean number of

130.89 holes and phostoxin also recorded the least means number of 0.00 exit hole followed by jatropha, turmeric alligator pepper with mean number of 46.53, 50.51, and 77.95 exit holes respectively (Tables 2).

Table 2. Effect of the pesticides on the mean number of exit holes created on the grains by cowpea weevils during restricted and unrestricted attack.

Treatments	Restricted	Unrestricted
Control	64.00	130.89
Wood ash	29.30	88.90
Grape peel powder	17.25	92.96
Ginger rhizome power	27.05	98.86
Moringa leaf powder	24.95	82.79
Scent leaf powder	35.85	102.86
Alligator pepper fruit powder	29.95	77.95
Phostoxin (synthetic fumigant)	0.00	0.00
Jatropha curcas leaf powder	22.85	46.53
Turmeric rhizome powder	14.81	50.51
F – LSD $_{(0.05)}$	14.85	45.64

Effect of pesticides on the mean weight loss of seeds (g) due to weevils attack.

There was significant treatment effect ($P \leq 0.05$) on mean weight loss of seeds (g) due to weevils attack. The control had the highest seed weight loss of 7.48g as a result of weevils attack, followed by wood ash that recorded 6.30g and moringa with 6.26g, while phostoxin recorded the least weight loss of 1.01g, followed by turmeric, ginger, scent leaf, jatropha, alligator pepper with 3.02g, 6.23g and 6.24g respectively (Table 3).

Table 3. Effect of the pesticides on the mean weight loss of seeds (g) due to weevils attack.

Treatments	Seed Weight Loss (g)
Control	7.48
Wood ash	6.30
Grape peel powder	6.24
Ginger rhizome power	6.20
Moringa leaf powder	6.26
Scent leaf powder	6.23
Alligator pepper fruit powder	6.24
Phostoxin (synthetic fumigant)	1.01
Jatropha curcas leaf powder	6.24
Turmeric rhizome powder	3.02
F – LSD $_{(0.05)}$	2.04

Effect of the pesticides on the mean number of eggs laid, mean number of exit holes by weevils and mean number of seeds infested by mold, twenty eight days after infestation (28 DAI).

The result of the experiment showed significant treatment effect ($P \leq 0.05$) on all the parmeters taken. Treatment eight (8) (Mancozeb + Acetamprid) being a combination of fungicide and insecticide, completely suppressed egg oviposition and fungal growth on cowpea seeds. The control recording a lower number of 96 eggs laid and higher exit holes of 95 than all the bio-pesticides used actually showed that bio-pesticides acted as luring agents (atractant) for eggs oviposition and at the same time poses detaring activities against egg hatching. Again, since there was no significant difference between treatment means of mancozeb + acetamprid (synthetic pesticide) and the bio-pesticides used, bio-pesticides could be used as better sustainable alternatives to synthetic pesticides against grain storage insect pests. On mold infestation of seeds, mancozeb + acetamprid recorded the least mean number of 0.00 infested seed, followed by alligator pepper, ginger, control and moringa with mean number of 1.00, 2025, 2.25 and 3.25 seeds respectively. The result of the experiment therefore suggests that those bio-pesticides that recorded higher means of mold infestation than the control should not be used to preserve grains in storage (Table 4)

Table 4. Effect of the pesticides on the mean number of eggs laid, mean number of exit holes by weevils and mean number of seeds infested by mold, twenty-eight days after infestation (28DAI)

Treatments	Number of Eggs.	Number of Exit Holes	Number of seeds Infested by mold
Control	96.00	85.00	2.25
Wood ash	207.00	28.20	4.00
Grape peel powder	211.00	16.80	10.25
Ginger rhizome power	206.00	31.20	2.25
Moringa leaf powder	199.00	9.80	3.25
Scent leaf powder	162.00	21.80	4.50
Alligator pepper fruit powder	174.00	10.20	1.00
Phostoxin (synthetic fumigant)	0.00	0.00	0.00
Jatropha curcas leaf powder	172.00	22.00	4.25
Turmeric rhizome powder	205.00	15.20	5.75
F – LSD $_{(0.05)}$	209.40	78.15	3.49

IV. DISCUSSION AND RECOMMENDATION

In the two experiments carried out, phostoxin being a synthetic fumigant insecticide exhibited a complete control of *Callosobruchus maculatus* (Cowpea weevils) in stored cowpea grains, and was closely followed by turmeric rhizome powder and grape peel powder which control effects were not significantly different from that of the phostoxin. Although, phostoxin is a well-known synthetic chemical used to protect grains against storage insect pests, it causes health hazards, poses residual effects and also not eco-friendly unlike bio-pesticides.

Traditionally, synthetic pesticides have been widely used to control pests like the cowpea weevils. These chemicals are often fast-acting and highly effective, making them an attractive option for farmers seeking to protect their stored produce (Pimentel, 2005). However, in response to the health risk chemical pesticide residues on food pose to consumers, particularly when used indiscriminately or inappropriately, bio-pesticides have emerged as promising alternatives. In view of this, I therefore recommend Turmeric rhizome powder and grape peel powder to be used in grain storage as sustainable approach to pest management.

This finding is in agreement with Isman, 2006 who stated that Bio-pesticides, derived from natural sources such as plants, bacteria and fungi, offer a more sustainable approach to pest management and are generally considered to be safer for human health and the environment compared to synthetic pesticides. He further gave *Azadirachta indica* an extract from plant like Neem as an effective pesticide in controlling a wide range of insect pests including the cowpea weevils. Also, Awere and Nkollo (2024) found Bio-pesticides as sustainable alternatives to synthetic pesticides in crop production.

The result of experiment one (1) showed that phostoxin, turmeric rhizome powder and grape peel powder exhibited significantly higher control of cowpea weevil, in restricted infestation than in unrestricted infestation. This research also revealed that turmeric powder and grape peel powder could be considered as potential bio-pesticide fumigants, since their pest control potency is higher in a closed environment than in an open one, just like phostoxin which is a well-known standard conventional synthetic fumigant pesticide in use today.

In the second experiment, fungal colonization of stored cowpea seeds differed significantly ($P \leq 0.05$) among treatment means. Mancozeb + acetamprid completely suppressed fungal infestation (0.00 infested seed, followed by Alligator pepper powder (1.00 infested seed) and Ginger (2.25 infested seeds). The result of this experiment therefore suggests that alligator pepper and ginger could be used to control fungal incidence in stored agricultural produce since their effect did not significantly differ from that of Mancozeb + acetamprid. It is also important to note in this experiment that some bio-materials such as grape peel powder, Turmeric, scent leaf, wood ash and moringa encourage mold infestation instead of suppressing it in stored produce, and therefore should not be used if the intention of the famer is to control storage mold.

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Global Climate Taxonomies and Indian Banking Sector: A Systematic Literature Review

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***Abstract*— *As countries accelerate their transition towards low-carbon economies, climate finance taxonomies have emerged as a critical policy instrument for channeling financial flows into environmentally sustainable activities. A climate finance taxonomy is defined as a structured framework to classify economic activities based on their alignment with climate objectives such as enhancing resilience and supporting transitions in carbon- intensive sectors. They provide common definitions and benchmarks to reduce greenwashing and enhance transparency (Network for Greening the Financial System, 2022). Most of the existing taxonomies, like UK, EU have been developed in advanced economies with market-oriented financial systems, hence raising questions about their relevance for emerging economies such as India. In India, banks dominate the financial system and play a pivotal role in financing infrastructure, industry and micro, small and medium enterprises (MSMEs) that are vital for growth yet highly carbon-intensive. India's Draft Climate Finance Taxonomy, released by the Ministry of Finance (MoF), in May 2025, seeks to address this challenge by guiding climate-aligned finance while clearly recognizing national development priorities and transition realities. The practical implications of the taxonomy for Indian banks are still underexplored. This study reviews a comparative literature of global climate finance taxonomies and finds their applicability to the Indian banking sector. Using a qualitative and comparative methodology, the study reviews international climate taxonomies' frameworks alongside India's draft taxonomy. The findings suggest that although global taxonomies provide valuable reference points for standardization and climate risk management, their direct transplantation into India's banking system may be inappropriate. India's Draft Taxonomy 2025, with its emphasis on transition pathways and development sensitivity, appears better aligned with domestic realities. This study has explored the literature on comparative evolution of climate finance taxonomies and their implications for India's bank-dominated financial system. The paper concludes with policy-relevant recommendations for regulators and banks to strengthen taxonomy implementation while advancing sustainable and inclusive economic growth.*

Keywords*— Climate Finance Taxonomy, Indian Banking Sector, Ministry of Finance, Global Taxonomies Comparison.

I. INTRODUCTION

Financial systems worldwide are increasingly expected to play a central role in enabling the transition towards low-carbon and climate-resilient economies. Therefore, climate finance taxonomies have emerged as critical policy instruments. They provide common definitions and benchmarks and so guide investors, banks and regulators (stakeholders) in identifying sustainable investments while reducing the risk of greenwashing through science-based criteria. They serve as instruments to align financial flows with environmental objectives and safeguard economic development. These frameworks have gained significant attraction in advanced economies, namely the United Kingdom (UK) and European Union (EU). They find the climate taxonomies as classification systems and policy tools that influence investment decisions, disclosure practices and risk management. But still the relevance for emerging economies with structurally different financial systems remains insufficiently examined (Grantham Research Institute on Climate Change and the Environment, 2025).

India's economy is predominantly bank-led, with commercial banks serving as the primary providers of long-term finance for infrastructure, industrial activity and MSMEs. (Reserve Bank of India, 2022). These sectors are vital for economic growth, employment and development but they also account for a substantial share of national greenhouse gas emissions. The studies have noted that designing climate finance frameworks that can steer capital towards sustainability without disrupting credit flows to growth-critical sectors poses a significant policy challenge for emerging economies (Bank for International Settlements 2023; Network for Greening).

The release of India's Draft Climate Finance Taxonomy: Consultation Document, by the Ministry of Finance (MoF), in 2023, marks an important initial step in addressing this challenge. The framework stresses the need for development sensitivity and gradual transition pathways with the aim to enhance the availability of capital for climate mitigation and adaptation. Yet, there are many institutional constraints as noted by a report by Asian Development Bank, 2022, and climate data related constraints noted by a report by Caldecott, B., Harnett, E., & Cojoianu, T. 2021. Also the constraints of translation of taxonomy guidelines into lending and risk assessment practices without undermining economic growth are highlighted (Ghosh & Sen, 2024; Banerjee, 2025; and reports by Organisation for Economic Co-operation and Development, 2023; Observer Research Foundation, 2024) etc.

Simultaneously, other countries are developing their frameworks too. Australia recently launched its Sustainable Finance Taxonomy through the Australian Sustainable Finance Institute (ASFI), in June 2025, supported by the government's Sustainable Finance Roadmap, called Australian Treasury 2025. The taxonomy emphasizes both green and transition finance. It structured to Australia's resource-intensive economy and provides a useful comparative case for India's draft framework.

Against this backdrop, the present study undertakes a comparative examination of some of the global climate finance taxonomies including India's draft framework 2025. By situating India's experience within broader global climate literature and experience on sustainable finance, this paper contributes to the growing body of literature on climate finance and offers policy-relevant insights for regulators and financial institutions in India.

II. LITERATURE REVIEW

[A]–Global and Regional Taxonomy Frameworks

>ASEAN Capital Markets Forum. (2021, November). *ASEAN taxonomy for sustainable finance: ASEAN capital market regulators' framework*.

It is the region's first unified, principles-based classification system, developed by the ASEAN Capital Markets Forum (ACMF), to guide capital market regulators, and other stakeholders, in mobilizing sustainable finance across ASEAN. With the aim to create a common language and to prevent greenwashing and align ASEAN's financial markets with the global sustainability goals. It provides ASEAN with a regional harmonization tool and offers strategic lessons for India's taxonomy development, especially in balancing inclusivity with credibility.

>Asian Development Bank. (2022, December). *Developing sustainable finance taxonomies in Asia*.

This report reviews taxonomy initiatives across Asia and recommends multi-tiered, transition-inclusive frameworks that recognise development priorities and institutional constraints in bank-dominated financial systems. It provides a framework to design, harmonize and implement sustainable finance taxonomies to mobilize capital for green and transition projects. It highlights the importance of aligning with global standards, while reflecting local priorities, especially in emerging markets.

>Australian Sustainable Finance Institute (ASFI). (2025, June 17). *Australia launches its sustainable finance taxonomy: A major milestone for green investment*.

Australia's taxonomy marks a major milestone in the Asia-Pacific region and fills a gap in sustainable finance infrastructure. It aims to establish a science-based classification system for sustainable and transition activities. It provides a common language for stakeholders and is designed to reduce greenwashing by setting clear eligibility criteria. It stresses the need for transition finance, similar to India's draft taxonomy. Although the adoption is voluntary, it is expected to influence disclosure and regulatory practices as well as harmonization with other taxonomies for cross-border investment.

>Australian Treasury. (2025). *Sustainable Finance Roadmap: Taxonomy overview*.

This government-led roadmap highlights the policy-regulatory interface, making it a valuable comparative case for India's the Ministry of Finance Draft Taxonomy 2025. It is linked to the launch of the Australian Sustainable Finance Taxonomy, ASFI, June 2025. It provides a foundation for disclosure requirements and regulatory alignment and provides clarity on eligible activities, reducing uncertainty for banks and investors. It seeks to mobilize private capital toward green and transition projects.

>European Commission Technical Expert Group on Sustainable Finance. (2020, March). *Final report on the EU taxonomy*. Brussels: European Commission.

The report laid the foundation for the European Union Taxonomy Regulation, including sector-specific screening criteria and the "Do No Significant Harm" (DNSH) principle. It represents one of the most comprehensive science-based sustainability classification systems globally. It defined technical screening criteria, environmental objectives and safeguards to classify sustainable economic activities. It became the basis for the European Commission's delegated acts and the official notification of the EU Taxonomy in June 2020.

>European Union. (2020, June 18). *Regulation (EU) 2020/852 of the European Parliament and of the Council on the establishment of a framework to facilitate sustainable investment*.

The framework established a binding European Union-wide classification system for environmentally sustainable economic activities, forming the backbone of Europe's sustainable finance framework. The core principles are- an activity must contribute to at least one of six environmental objectives; DNSH principle - activities must not harm other objectives; and compliance with Organisation for Economic Co-operation and Development (OECD) Guidelines and UN Guiding Principles (UNGPs), on Business and Human Rights.

>HM Government, UK. (2023, March). *Green finance strategy: Mobilising green investment*.

It is a benchmark document for countries designing taxonomies and transition finance frameworks. For India, it provides lessons on- nature-positive finance integration (biodiversity, ecosystems), global positioning as a sustainable finance hub, and disclosure alignment with OECD safeguards. It complements India's draft Taxonomy 2025, which is benchmarking EU and UK frameworks while adapting for MSMEs inclusion.

>Organisation for Economic Co-operation and Development. (2023, May). *Climate finance taxonomies: Best practices for emerging economies*.

The OECD's report is an essential document that provides guidance for emerging economies on designing and implementing climate finance taxonomies that are credible, interoperable and aligned with global best practices. The clear definitions of green and transition finance, institutional capacity building, need for balancing development priorities with climate goals, encouraging private sector participation in taxonomy development, flexibility to adapt to local contexts while ensuring comparability are suggested.

>Network for Greening the Financial System. (2022, October). *Guidance on transition finance*.

NGFS is a global framework, consisting of a coalition of central banks to integrate climate risks into financial regulation, founded in 2017, Paris. This report is the key guidance document for transition finance, focusing on credibility, disclosure and supervisory alignment. It highlights encouraging regulators to embed climate considerations into macroprudential policies, particularly in emerging economies.

[B]--Indian Regulatory and Policy Documents

>Reserve Bank of India. (2022, July). *Discussion paper on climate risk and sustainable finance*.

It is a landmark document that sets out regulatory expectations for Indian banks and financial institutions to integrate climate-related risks into governance, strategy, risk management and disclosures. It highlights the systemic implications of climate change for financial stability and intends to gradually integrate climate considerations into banking supervision and also proposes a roadmap for sustainable finance in India.

>Reserve Bank of India. (2024, February). *Climate risk and disclosure framework*.

It is a landmark framework by the RBI, for banks, NBFCs and financial institutions to operationalize climate risk management in India's banking system. It directly supports the draft Climate Finance Taxonomy (MoF, 2025) by creating disclosure and supervisory infrastructure. This marks India's first regulatory step to integrate climate-related financial risks into supervision, requiring disclosures, stress testing and alignment with global standards like NGFS and EU Taxonomy. RBI 2024 provides the regulatory backbone linking empirical studies (Iyer & Narain 2021), transition finance (TERI 2023), taxonomy design (ORF 2024), and systemic financing (IEEFA 2025).

>Ministry of Finance, Government of India. (2023, October). *Draft climate finance taxonomy: Consultation document*.

It presents India's initial approach to climate finance classification, emphasising development sensitivity, transition pathways and financial stability. It aimed at enhancing the availability of capital for climate mitigation and adaptation.

>Ministry of Finance, Department of Economic Affairs. (2025, May). *Draft climate finance taxonomy*.

This is India's most significant step toward sustainable finance regulation as it formalises India's classification of green and transition activities, balancing decarbonisation objectives with economic growth and financial stability in a bank-dominated economy. It invites public and expert comments, aiming to align the global frameworks like EU, ASEAN, OECD, UNGPs, with India's domestic priorities. It aims to facilitate greater resource flow to climate-friendly technologies and activities and mobilize capital for India's net-zero 2070 target.

>The Energy and Resources Institute. (2023, November). *Designing a transition finance framework for India*.

The report is one of the first India-specific structured approaches, with the objective to create a transition finance framework while ensuring equity and inclusion. It emphasizes just the transition principle while maintaining economic growth, sectoral pathways (coal, steel, cement), public–private coordination and the need for a taxonomy-linked framework to mobilize capital.

>Observer Research Foundation. (2024, June). *Designing India's climate finance taxonomy*.

It is one of the first structured proposals for India's taxonomy framework. The report emphasizes sectoral alignment, MSMEs inclusion and benchmarking against global taxonomies (EU, UK). It directly informed India's MoF draft taxonomy released in 2025. It provides a blueprint for India to classify, regulate and mobilize climate-aligned investments. It emphasizes preventing greenwashing. It advocates a principles-based, transition-inclusive taxonomy aligned with RBI regulation and development priorities and banking-sector realities, arguing that flexibility is essential for effective adoption in a bank-dominated financial system.

[C]--Scholarly and Analytical Contributions (India-focused)

>Banerjee, R. (2025). *Sustainable Banking and Climate Taxonomy Adoption in India.*

This is one of the first India-focused empirical studies on taxonomy adoption in banks, with the aim to examine regulatory readiness, sectoral inclusion and the challenges of taxonomy adoption across India's financial system. Using qualitative analysis of public and private bank disclosures, policy documents and interviews with banking professionals and aligning with the MoF's draft Climate Finance Taxonomy May 2025. It explores the impact on sustainable banking practices, including Environment, Social and Governance (ESG) disclosures, green lending and risk management. The study identifies institutional inertia, climate data limitations, complementing Caldecott, B., et. 2021 report and weak supervisory integration as major barriers to effective taxonomy-driven credit allocation.

>Ghosh, A., & Sen, R. (2024, May). *Implementing climate finance taxonomies in Indian banks*.

The study analyses the practical institutional and operational challenges faced by Indian banks in implementing the climate finance taxonomy framework. Key issues include limited availability of reliable climate and emissions data, weak integration of taxonomy criteria into credit appraisal and risk management systems and insufficient internal capacity within banks to interpret technical screening standards. It concludes that effective implementation requires regulatory clarity, capacity building, and phased adoption tailored to India's banking structure.

>Grantham Research Institute on Climate Change and the Environment. (2025, January). *Seven lessons for India's climate finance taxonomy*.

The study is particularly useful for the paper because it anchors India's taxonomy design in global best practice. It complements ORF (2024), RBI (2022) (2024), TERI (2023) and Banerjee (2025). The study provides guidance to India's Department of Economic Affairs, MoF, on shaping its draft taxonomy. It draws on global best practices and emphasizes credibility, inclusivity and safeguards against greenwashing. It highlights India's strengths in development sensitivity and transition orientation, while identifying data and banking-sector implementation challenges. The seven lessons identified by the study for India are:

Clear Objectives: Define taxonomy goals (mobilizing finance, preventing greenwashing, supporting net-zero 2070).

Alignment with National Priorities: Integrate with India's National Determined Contributors (NDCs), sectoral missions and developmental needs.

Sectoral Coverage: Cover power, mobility, buildings, agriculture, food security, water security, and hard-to-abate industries.

Social & Equity Dimensions: Ensure MSME inclusion and just transition principles.

Credibility & Transparency: Require robust disclosure, verification and monitoring mechanisms.

Phased Implementation: Begin with priority sectors, expand gradually to full economy-wide coverage.

Global Benchmarking: Learn from EU, China, Japan taxonomies while adapting to India's context.

>Institute for Energy Economics and Financial Analysis (IEEFA). (2025, February). *Bridging India's climate finance gap*.

IEEFA report highlights that India faces a massive climate finance shortfall, estimated at over US$ 10–11 trillion through 2070. It complements TERI (2023) and ORF (2024) by showing the financing scale and systemic models required to operationalize India's taxonomy. It argues for blended finance, India's stronger policy frameworks to mobilize investment across energy, infrastructure and MSMEs.

>Iyer, K., & Narain, S. (2021). *Climate change and financial stability: The Indian banking perspective*. Mumbai: RBI Publications.

It is a foundational Indian study linking climate change to banking stability, with empirical evidence (2002–2019 data). Accordingly, India's taxonomy 2025 draft must integrate with RBI's supervisory framework and global initiatives like NGFS and EU Taxonomy. It agrees with the report by Bolten, 2020, by supporting the financial stability rationale behind India's taxonomy design. The study analyses the climate risks, both physical (disasters, extreme weather) and transition (policy shifts, stranded assets), pose systemic threats to India's banking sector. And finds the regulatory gaps, systemic vulnerabilities and the urgent need for climate-aligned clearer regulatory and financial strategies.

[D]--Central Banking and Financial Stability

>Bank for International Settlements. (2023, September). *Sustainable finance and the role of financial regulation*.

It highlights the role of regulators in integrating climate risk into supervisory frameworks, strengthening disclosure standards, and mobilising capital for green transition. It emphasizes the need for regulatory innovation to align financial flows with sustainability goals. RBI's Discussion Paper 2022, already aligns with BIS recommendations on governance, risk management and disclosures. It provides a regulatory blueprint that complements OECD 2023 and RBI efforts in sustainable finance.

>Bolton, P., Després, M., Pereira da Silva, L. A., Samama, F., & Svartzman, R. (2020, January). *The green swan: Central banking and financial stability in the age of climate change*.

This landmark report published by BIS, reviews ways of addressing the risks due to climate change within central banks' financial stability mandate. It includes climate mitigation policies such as carbon pricing, the integration of sustainability into financial practices and accounting frameworks, the search for appropriate policy mixes and the development of new financial mechanisms at the international level. They are essential to preserve long-term financial and price stability in the age of climate change. Here, the "green swan" means extremely financially disruptive events that could be behind the next systemic financial crisis.

>Caldecott, B., Harnett, E., & Cojoianu, T. (2021, October). *Delivering the transition: The value of climate-related data for financial decision making*.

The report highlights the importance of high-quality climate data for guiding capital flows, managing risks and enabling credible transition pathways. It provides a global benchmark for India's taxonomy design 2025, which must integrate robust climate data systems to avoid greenwashing.

2.1. Literature Synthesis and Research Gaps

The existing literature is establishing climate change as a systemic financial risk and in developing climate finance taxonomies as instruments of standardisation, transparency and risk management as observed by these studies also (Bolton, et al. 2020; European Union, 2020; Bank for International Settlements, 2023). Since 2020, studies have increasingly highlighted the importance of transition finance, proportionality and alignment with domestic financial systems, particularly in emerging economies and complemented by these reports also (Asian Development Bank, 2022; Organisation for Economic Co-operation and Development, 2023; Network for Greening the Financial System, 2022; Bank of International Settlement, 2023) etc. However, much of the global taxonomy literature remains grounded in market-based financial systems, offering limited guidance for bank-dominated economies.

India's economy relies heavily on banks for long-term financing of infrastructure, industry and MSMEs (RBI, 2022, 2024). And within the banking sector, Indian-focused studies are identifying the data constraints, institutional capacity limitations, and regulatory uncertainty (Iyer & Narain, 2021; RBI, 2022, 2024 and Ghosh & Sen, 2024). The studies by Observer Research Foundation, 2024; Grantham Research Institute, 2025; Ministry of Finance, 2023; 2025; The Energy and Resources Institute, 2023 underscore the development-sensitive and transition-oriented nature of India's draft taxonomy

Yet, there remains a lack of systematic examination of how taxonomy guidelines can be operationalised by banks, particularly in credit appraisal, portfolio risk management, and disclosure practices (Banerjee, 2025; Ghosh & Sen, 2024; Institute for Energy Economics and Financial Analysis, 2025) etc. Therefore, adaptation requires balancing growth imperatives with decarbonisation, ensuring proportionality in application and embedding transition finance pathways (TERI, 2023; ORF, 2024).

At the same time, comparative experiences from other countries provide valuable insights. The European Union taxonomy offers a mandatory, disclosure-driven framework (European Union, 2020), while the UK's Green Finance Strategy emphasizes proportionality and interoperability (HM Government, 2023). Australia's Sustainable Finance Taxonomy (Australian Sustainable Finance Institute, 2025) and accompanying Sustainable Finance Roadmap (Australian Treasury, 2025) highlight the centrality of transition finance in resource-intensive economies. These frameworks illustrate both transferable principles and the need for contextual adaptation in emerging markets.

- While global frameworks offer valuable experience (European Union, 2020; HM Government, 2023), direct transplantation may be ineffective. India must selectively adapt global practices, prioritising proportionality, development sensitivity and financial inclusion (ASEAN, 2021; ADB, 2022; ORF, 2024).
- A well-adapted taxonomy can help India simultaneously pursue climate alignment and economic development, especially if it embeds flexibility for high-emission but growth-critical sectors (TERI, 2023; NGFS, 2022; OECD, 2023). This balance is essential for maintaining credit flows while steering capital toward sustainability.

III. DERIVED IMPLICATIONS

- India's bank-led financial system differs fundamentally from market-based systems where initial global taxonomies originated (EU, UK). Therefore, the taxonomy frameworks must be tailored to accommodate the operational realities of Indian stakeholders, particularly banks' role in financing MSMEs, infrastructure and industrial sectors (HM Government, UK, 2023; RBI, 2022; Iyer & Narain, 2021).
- The emphasis on transition finance in India's draft taxonomy (MoF, 2023; MoF, 2025) aligns with global trends (ASFI, 2025 and OECD, 2023) but its implementation requires clear regulatory guidance and sector-specific pathways otherwise, the banks may struggle to integrate taxonomy criteria into credit appraisal and risk management without institutional clarity (Banerjee, 2025 and Iyer, 2021).
- Effective taxonomy adoption depends on efficient data systems and disclosure frameworks, which remain underdeveloped in India's banking sector (Ghosh & Sen, 2024). Hence, according to BIS, 2023, strengthening ESG data availability and standardised reporting will be essential for meaningful taxonomy integration
- In the absence of regulatory mandates or incentives, banks may adopt taxonomy labels symbolically without altering lending behaviour (Grantham Research Institute, 2025).

  So, the policymakers must design mechanisms that encourage substantive integration, such as prudential incentives, capacity-building and supervisory alignment (NGFS, 2022; OECD, 2023).

IV. POLICY RECOMMENDATIONS

Drawing on the comparative analysis of literature of global taxonomies and India's draft framework, several policy recommendations emerge for regulators, banks and policymakers. These recommendations would ensure that taxonomy adoption in India's bank-dominated financial system is substantive, development-sensitive and aligned with climate goals.

- The Reserve Bank of India and Ministry of Finance should provide clear supervisory guidance on taxonomy implementation. Regulatory incentives, like preferential risk weights or capital relief for taxonomy-aligned lending, can encourage banks to move beyond symbolic adoption and integrate taxonomy criteria into credit appraisal and portfolio management (RBI, 2022; BIS, 2023; Banerjee, 2025; Ghosh & Sen, 2024).
- Taxonomy adoption requires reliable ESG data and standardized disclosure formats. Establishing centralized ESG data repositories and mandating uniform reporting aligned with international frameworks (EU taxonomy, NGFS guidance) will reduce information asymmetry and enhance transparency (BIS, 2023; Ghosh & Sen, 2024).
- Although, India's draft taxonomy emphasizes transition finance but operational clarity is required. Sector-specific transition criteria should be developed for high-emission yet growth-critical industries such as infrastructure and MSMEs (IEEFA, 2025). Phased targets and proportional requirements will allow banks to gradually integrate taxonomy guidelines without disrupting credit flows (MoF, 2023; ASFI, 2025).

- Training programs for credit officers and risk managers are essential to embed taxonomy principles into lending practices. Partnerships with academic institutions and think tanks (TERI, 2023; ORF, 2024; BIS, 2023; Grantham Research Institute, 2025) can strengthen technical expertise and foster innovation in climate-aligned banking.
- India should selectively adapt global practices rather than transplant them wholly. The EU's disclosure-driven rigor, the UK's proportionality and Australia's transition-finance emphasis provide useful principles but must be tailored to India's bank-dominated system and development priorities (European Union, 2020; HM Government, 2023; ASFI, 2025).
- Taxonomy criteria should explicitly account for MSME financing, rural development and equity considerations. Aligning taxonomy adoption with India's broader development goals like, employment, infrastructure and financial inclusion, will ensure that climate objectives do not undermine growth imperatives (RBI, 2024; TERI, 2023; ASEAN,2021).
- Independent oversight bodies should be created to track taxonomy implementation and prevent greenwashing. Regular updates to taxonomy criteria will be necessary to reflect evolving science, technology and sectoral realities (NGFS, 2022; OECD, 2023).

V. CONCLUSION

This study has explored the literature on comparative evolution of climate finance taxonomies and their implications for India's bank-dominated financial system. The systematic literature review shows that while global frameworks such as the EU taxonomy (European Union, 2020), the UK's Green Finance Strategy (HM Government, 2023), and Australia's Sustainable Finance Taxonomy (Australian Sustainable Finance Institute, 2025; Australian Treasury, 2025) provide valuable insight, their direct transplantation into India's financial system is neither feasible nor desirable. Instead, India's draft taxonomy (Ministry of Finance, Government of India, 2023; Ministry of Finance, Department of Economic Affairs, 2025) reflects a development-sensitive and transition-oriented approach, tailored to the realities of the Indian economy.

The literature review of this paper highlights the mediating role of institutional capacity, regulatory clarity and sectoral constraints in shaping taxonomy adoption pathways. Without robust ESG data systems, standardized disclosure mechanisms and regulatory incentives, Indian banks risk adopting taxonomy labels symbolically rather than substantively (Banerjee, 2025; Ghosh & Sen, 2024). Comparative literature underscores the importance of balancing rigor with proportionality, embedding transition finance pathways and ensuring inclusivity for MSMEs and growth-critical sectors (TERI, 2023; OECD, 2023; NGFS, 2022).

Ultimately, India's taxonomy can serve as a strategic instrument to align financial flows with its net-zero 2070 commitment and safeguarding developmental imperatives too. Achieving this balance requires coordinated action by regulators, banks and policymakers to strengthen institutional capacity, embed transition pathways and align taxonomy adoption with broader financial sector reforms.

By bridging global principles with India's unique financial architecture, this study contributes to the emerging discourse on climate-aligned banking in developing economies. Future research should examine taxonomy-linked financial instruments, sector-specific transition benchmarks and blended finance mechanisms that can scale taxonomy-aligned lending in India and other emerging markets.

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Phylogenetic and morphometric observations of the *Periplaneta americana* (L.) gut microbiome from collections of Gaya Ji region

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***Abstract*— *In Indian urban habitats, especially Gaya, the American cockroach, Periplaneta americana (L.), is a common synanthropic bug. Because of its scavenging behavior, P. americana frequently harbors a variety of intestinal nematodes that are significant from an epidemiological standpoint. In order to establish a thorough account of nematode parasites associated with the gut microbiome of P. americana from an Indian perspective, this study synthesizes available parasitological data and integrates morphological and phylogenetic insights derived from recent observations, with an emphasis on the applicability of these findings to Gaya.*

***Keywords*— Nematodes, Parasites, American Cockroach, Gaya.**

I. INTRODUCTION

Study of insect-parasitic nematodes serves three purposes. First, it expands knowledge of biodiversity in poorly examined host groups. Second, it contributes to host–parasite ecology by revealing how parasites persist in insect populations. Third, it provides material for systematics and phylogeny, particularly where host association helps interpret nematode relationships. Although entomopathogenic genera such as Steinernema and Heterorhabditis attract attention for biological control, the intestinal oxyurids of cockroaches remain significant for taxonomy, ecology, and biodiversity documentation (Adams and Nguyen 2008).

In India, insect-parasitic nematodes have received less sustained attention than plant-parasitic or soil nematodes. Several classical records predate molecular tools, and many require reassessment through integrative methods. Regional surveys supported by molecular data are therefore needed to strengthen the taxonomy of insect-associated nematodes.

The phylogenetic diversity of insect-parasitic nematodes provides opportunities for comparative biology. By sequencing nematodes from different host groups and regions, researchers can reconstruct the evolutionary history of host–parasite associations. Such comparative frameworks have been constructed for some nematode groups (Blaxter et al. 1998; Holterman et al. 2006), but *thelastoma*tids remain under-represented relative to their ecological importance. The hindgut of *P. americana* is a biologically active compartment containing host tissues, dietary residues, and dense microbial communities. For intestinal nematodes, it offers protection from external conditions and continuous access to nutrients, but it also imposes constraints: limited space, competition, peristalsis, and dependence on host behaviour for transmission. The hindgut can support more than one nematode species simultaneously. Connor and Adamson (1998) demonstrated niche overlap among pinworms in the hindgut of *P. americana* and showed that multiple species coexist in this confined intestinal space.

Leidy (1849, 1850) was among the earliest workers to describe nematodes from invertebrate hosts, establishing the genus *Thelastoma*. Hammerschmidt (1838) contributed early descriptions of forms later placed in *Hammerschmidtiella*. Travassos (1929) formalised the classification of oxyuroid nematodes at the family level. Chitwood (1932) then produced a major synopsis of nematodes parasitic in insects of the family Blattidae, connecting nematode morphology with cockroach hosts and providing a framework for later workers.

Connor and Adamson (1998) showed that multiple pinworm species can coexist in the cockroach hindgut through partial spatial and temporal separation. The present findings support this interpretation: the three major genera differ in body size (*Thelastoma* largest, *Schwenkiella* smallest), anterior-end morphology, and tail form, suggesting possible microhabitat differentiation within the posterior gut.

II. MATERIALS AND METHODS

This investigation was designed as an integrative taxonomic study of nematode parasites from *Periplaneta americana* collected in Gaya, Bihar. The work combined field collection, laboratory dissection, microscopic examination, morphometric recording, DNA extraction, PCR amplification of ribosomal markers, sequencing, and phylogenetic analysis. The target genera were *Hammerschmidtiella, Thelastoma, Leidynema,* and *Schwenkiella,* all *thelastomatid* oxyurids.

Both morphological and molecular markers were used because *thelastomatid* nematodes may show overlapping diagnostic characters, and several older records were based only on morphology (Adamson and Van Waerebeke 1992; Jex et al. 2006). The methodological framework was intended to verify whether recovered nematodes could be assigned confidently to known genera and representative species and whether molecular placement agreed with morphological identity.

Adult *P. americana* were collected manually or by baited traps during evening and night hours. Specimens from each site were kept separately in labelled, ventilated containers. Damaged or dead cockroaches were excluded. A total of 200 adult cockroaches were examined. Identification followed the diagnostic characters of Bell, Roth, and Nalepa (2007): large body size, reddish-brown colour, flattened body form, long antennae, spiny legs, fully developed tegmina, and a pale yellowish pronotal margin. Nymphs and uncertain specimens were excluded.

For each host, infection status, number of worms recovered, and preliminary genus-level identity were recorded. Mixed infection was noted when more than one genus occurred in the same host. Prevalence, mean intensity, and mean abundance were calculated as:

Prevalence (%) = (Number of infected hosts / Total hosts examined) × 100

Mean intensity = Total parasites recovered / Number of infected hosts

Mean abundance = Total parasites recovered / Total hosts examined

III. RESULT AND DISCUSSION

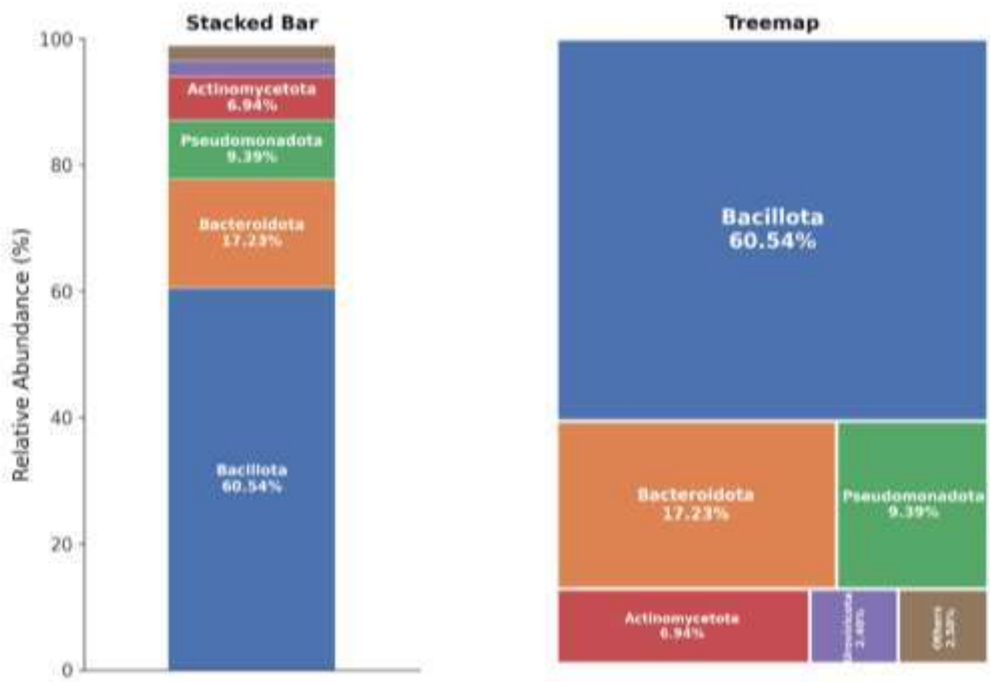
The associated cockroach gut microbiome provides the verified molecular publication component. It reported a complex hindgut community dominated by Bacillota (60.54%), followed by Bacteroidota (17.23%), Pseudomonadota (9.39%), and Actinomycetota (6.94%).

Table :1. Phylum-level composition of the P. americana gut microbiome.

Phylum	Relative Abundance (%)	Read Count	Observation
Bacillota	60.54	2,331,212	Dominant phylum in the hindgut community
Bacteroidota	17.23	663,352	Second most abundant phylum
Pseudomonadota	9.39	361,743	Fermentative and succinate-producing groups
Actinomycetota	6.94	267,402	Moderately abundant phylum
Uroviricota	2.40	Not specified	Viral/bacteriophage component
Thermodesulfobacteriota	1.00	Not specified	Minor phylum
Euryarchaeota	0.70	Not specified	Methanogenic archaeal component

Table: 2. Dominant taxa and diversity in the cockroach gut microbiome.

Taxonomic Level	Dominant/Important Taxa	Reported Value	Interpretation
Family	Oscillospiraceae	24.72%	Major fermentative family
Family	Lachnospiraceae	24.65%	Co-dominant fermentative family
Genus	*Bacteroides*	8.10%	Most abundant genus
Genus	*Vescimonas*	7.83%	Highly represented gut-associated genus
Genus	*Blautia*	6.77%	SCFA-associated fermentative genus
Species	*Bacteroides fragilis*	4.52%	Most abundant species
Species	*Vescimonas coprocola*	4.45%	Second most abundant species
Diversity	64 phyla; 584 families; 2,018 genera	–	High taxonomic richness



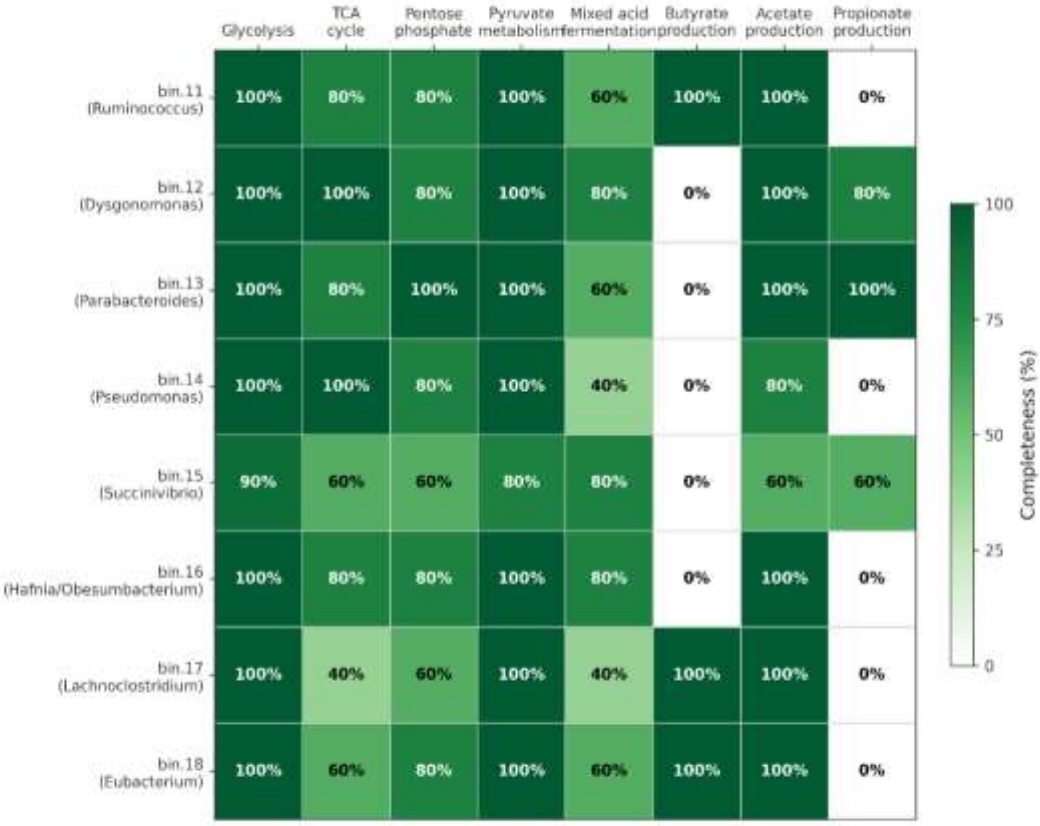
Histogram: 1. Multi-level taxonomic composition of the P. americana gut microbiome from the associated cockroach gut microbiome.

The overall prevalence of 84.0% (168/200) confirms that *P. americana* in Gaya sustains active nematode transmission. This value is comparable to high-prevalence records from other Indian and global studies. Basir (1956) noted regular occurrence of *thelastomatids* in Indian cockroaches, and Shah (2007) reported frequent infection in cockroaches from Manipur. Internationally, Jex et al. (2006) found *thelastomatids* in a large proportion of Australian cockroaches examined for molecular work, and Blanco et al. (2012) recorded *H. diesingi* consistently from *P. americana* in Argentina.

Infection was highest in restrooms and toilets (91.4%), followed by garbage and waste areas (88.6%), kitchens (87.5%), and storehouses (85.7%). Lower prevalence occurred in damp soil and outdoor crevices (72.0%) and miscellaneous localities (73.3%). This gradient reflects the relationship between habitat moisture, organic matter, host density, and egg survival.

Morphological Interpretation

Morphological characters successfully separated the four genera. *Hammerschmidtiella* (2.35–3.12 mm body length) was identified by its triradiate stoma, filiform tail (280–350 µm), and slightly posterior vulva (52–56%). These measurements fall within the range reported for *H. diesingi* by Blanco et al. (2012), who measured body lengths of 2.2–3.5 mm in Argentinian material, and by Basir (1956) for Indian specimens.



Histogram: 2. Heatmap of key metabolic pathway completeness across eight MAGs from the associated cockroach gut microbiome.

Thelastoma (4.20–5.85 mm) was distinguished by its prominent buccal cavity (20–25 µm depth), muscular bulb, and tapering tail (350–450 µm). The larger body and deeper buccal cavity separate it clearly from *Hammerschmidtiella*. These characters are consistent with *T. periplaneticola* descriptions from Shah (2007) and Spiridonov and Guzeeva (2009).

Leidynema (3.85–4.92 mm) was characterised by its elongated stoma (18–22 µm), deeper cervical annulations, and conical tail (180–230 µm). The conical tail, in contrast to the filiform tail of *Hammerschmidtiella* and the tapering tail of *Thelastoma*, provides a reliable field character. These morphometrics agree with *L. appendiculata* descriptions from Ozawa et al. (2014).

The morphological results demonstrate both the value and the limits of classical taxonomy. While genus-level separation was achievable, measurements overlap between genera (e.g., body width ranges overlap for *Hammerschmidtiella* and *Schwenkiella*), and damaged or immature specimens could be difficult to assign. This reinforces the need for molecular confirmation, a conclusion shared by recent integrative studies in nematode taxonomy (Cantalapiedra-Navarrete et al. 2024; Munawar et al. 2024; Salazar-García et al. 2025).

IV. CONCLUSION

The high prevalence is explained by the ecology of both host and parasite. *P. americana* is nocturnal, omnivorous, aggregation-prone, and tolerant of unsanitary environments. Nematode eggs pass with host faeces and are ingested by other cockroaches during feeding or substrate contact. This direct life cycle, combined with high host density in indoor habitats, creates favourable conditions for sustained transmission.

The finding that uninfected hosts constituted only 16.0% of the sample suggests either efficient re-infection or that the hindgut environment is so consistently suitable that clearance is rare. In either case, *P. americana* in Gaya functions as a reliable reservoir for *thelastoma*tid nematodes.

Prevalence values for *thelastoma*tids in *P. americana* tend to be high (>50%), supporting the general conclusion that this host–parasite association is biologically robust. The consistency of high prevalence across different localities within Gaya (range: 72.0–91.4%) further supports this interpretation.

P. americana from Gaya, Bihar, harboured a diverse assemblage of *thelastoma*tid nematodes. The overall infection prevalence was 84.0% (168/200). *Hammerschmidtiella* was the dominant genus (68.5%), followed by *Thelastoma* (51.5%), *Leidynema* (40.5%), and *Schwenkiella*-like forms (16.0%). Infection was highest during the monsoon season.

From an epidemiological perspective, the 84.0% prevalence should be interpreted alongside other parasitological parameters. Mean intensity (average number of parasites per infected host) and mean abundance (average number per all examined hosts) would further characterise the infection level but require accurate worm counts that may be affected by the difficulty of recovering all small worms from gut contents. Nevertheless, the prevalence alone is sufficient to establish that *P. americana* populations in Gaya maintain a high baseline level of *thelastomatid* infection.

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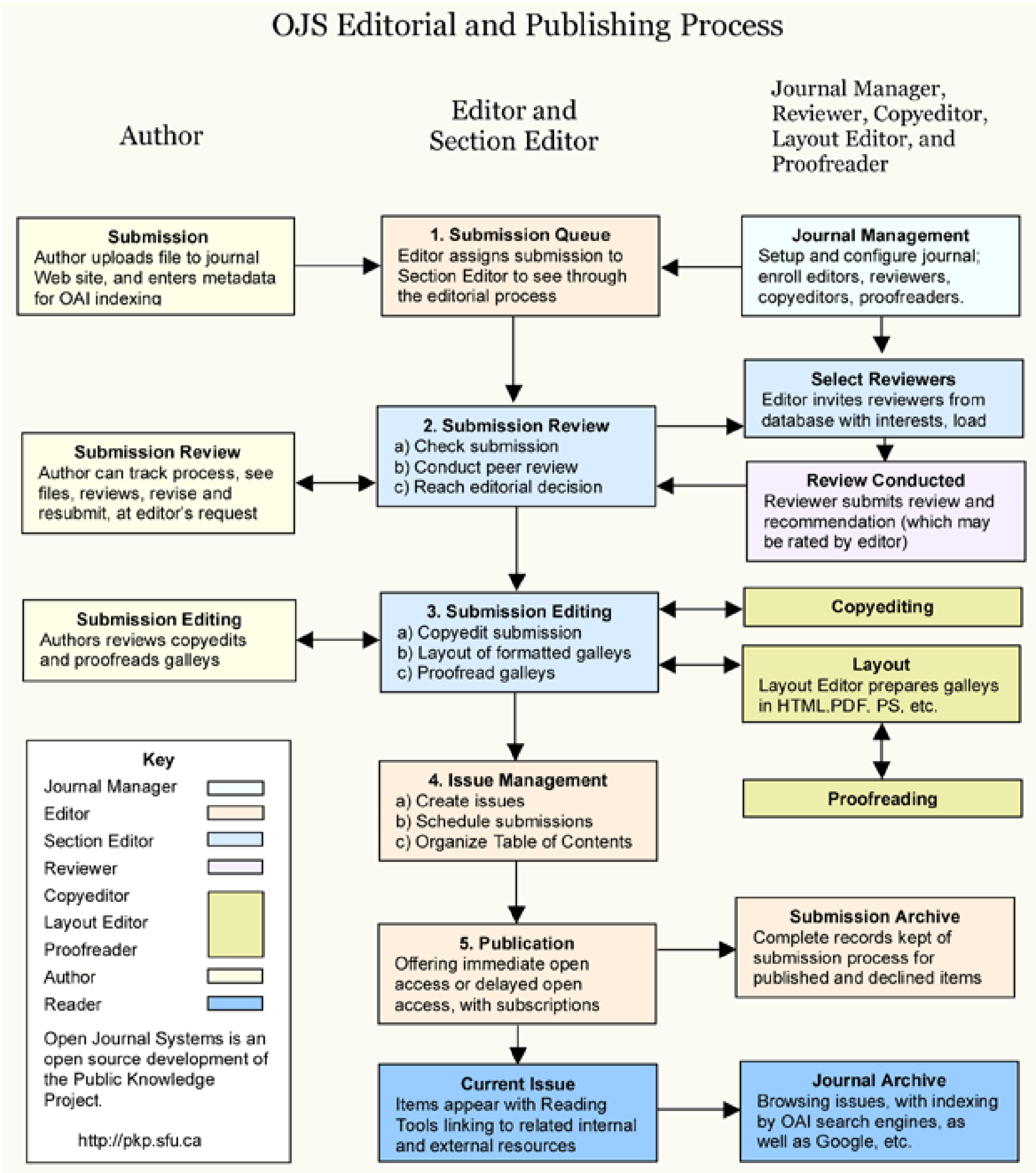

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