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VOLUME-11, ISSUE-8, AUGUST 2025

Preface

We would like to present, with great pleasure, the inaugural volume-11, Issue-8, August 2025, of a scholarly journal, *International Journal of Environmental & Agriculture Research*. This journal is part of the AD Publications series *in the field of Environmental & Agriculture Research Development*, and is devoted to the gamut of Environmental & Agriculture issues, from theoretical aspects to application-dependent studies and the validation of emerging technologies.

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

Environmental Research:

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

Agriculture Research:

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

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

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Release of Plant Essential Nutrients from Yagya Ash and Impact on Pea (*Pisum sativum*) Growth

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Abstract— *This study investigates the agricultural benefits of Yagya (Agnihotra) by analysing the release of essential plant nutrients from Yagya ash and its impact on the growth of pea (Pisum sativum). Incubation experiments and pot trials with Yagya and wood ash were conducted. Incubation study revealed that all treatments were able to improve the soil fertility. Maximum organic carbon, available phosphorus and available potassium were obtained in treatment YA5 and WA6 (0.93% and 1.05%), YA6 and WA6 (159.04 kg/ha and 215.04 kg/ha) and YA6 and WA6 (280.8 kg/ha and 374.6 kg/ha). Available Sulphur was increased by 14.1 to 140.8 and 3.8 to 33.3-fold in Yagya ash and wood ash treatments. pH and electrical conductivity of the soil increased initially in all treatments and normalized at the end of the incubation study in Yagya ash whereas neutral pH was not attained for wood ash treatments. FTIR characterization of ash shows the presence of carboxylic acids, alkenes and alcohols. No significant changes were observed between the surface morphologies of the ash samples before and after incubation. Likewise, pot trials results revealed that Yagya ash improved the plant growth and yield. Maximum seed germination (73.3%), plant length (78.5 cm), plant biomass (29.2g), nodules (20), pod length of 9.37 cm were observed in treatment T5 (Yagya ash + chemical). Additionally, Yagya ash application with organic and inorganic inputs improved the plant nutrients. Findings suggest that Yagya ash can serve as an effective organic fertilizer, promoting sustainable agriculture by enhancing nutrient availability and plant growth.*

Keywords— Yagya ash, organic farming, incubation, wood ash, pea.

I. INTRODUCTION

Recent increases in crop productivity worldwide have been mainly accomplished by increased chemical fertilizer inputs and if food demand rises in the future, it is expected that this input will rise even more [1]. The realization that the rhizosphere and biosphere have been somewhat neglected in the conventional chemical agriculture makes sustainable agriculture the top focus. The environment, soil health and yield quality have all suffered as a result of the indiscriminate use of agrochemicals in recent decades [2].

A healthy soil is essential for producing healthy crops, which in turn improves human welfare. Soils that are nutrient-deficient and contaminated have a significant impact on plant growth and human health. According to current reports, the majority of Indian soils have low organic carbon contents, less than 0.5 percent as well as other nutritional deficiencies. Searching for economically viable, environmentally sound, technically feasible and accessible approaches is essential to maintaining soil fertility. Replacing synthetic fertilizer with renewable organic sources is one way to potentially address these issues [3]. Managing locally available organic resources has proven to be the best way of action. However, the nutrient content of the organic source and nutrient release behaviour in the soil determine appropriateness of the organic sources. Using incubation studies with soil in its natural environment to examine the pattern of nutrient release is one way to determine the compatibility of any organic source. Furthermore, it is crucial to create a strong, useful and appropriate package of nutrient management employing organic resources for various crops based on data from trials, local conditions and economic viability.

Conventional wood ash that is frequently seen as waste, can be applied to soil as a liming agent and to correct nutrient imbalances or deficiencies in forests [4]. Ash applications have been shown to improve soil nutrient content and microbial activity, mineralization, and nitrification [5,6]. According to studies conducted in the field and in greenhouses, ash treatments have significantly increased the physical, chemical and biological properties of the soil [7,8]. This has also improved the plant growth [9]. However, the conventional wood ash contains heavy metals and other pollutants from the source [10]. Yagya or Agnihotra ash, which is infused with the medicinal qualities of wood and other materials used in Yagya, could be employed to get over this limitation. Yagya ash is known to have a good quantity of soil nutrients. Yagya is a practice that is carried out in many nations worldwide. Despite being an age-old fire ritual, it involves burning dried cow dung, unpolished rice, cow butter and medicinal wood like mango etc. in a copper vessel that is typically shaped like an inverted pyramid. Yagya has been traditionally associated with spiritual and environmental benefits. Yagya ash and fumes from Yagya are beneficial for agriculture, water and air purification, lowering the pathogenicity of bacteria and enhancing the health of living things. In addition to being recognized to support plant growth, this ash is used to treat a wide range of ailments. In certain early trials, it has been shown to reduce pest and insect attack, improve seed germination, and neutralize damaging radiations. However, long-term, in-depth field studies supported by scientific data are still lacking.

Focussing the appropriateness of Yagya ash in supplying plant essential nutrients, an incubation study with Yagya ash and wood ash at different doses was conducted in sandy loam soil. Pot trials at optimum ash dose obtained by incubation study were conducted. The main objectives were i) to quantify and compare the phytoavailable nutrient release from ash at different doses ii) understand the mechanism of release by investigating ash surfaces before after incubation, iii) impact of ash on pea plant growth and yield.

II. MATERIALS AND METHODS

2.1 Collection of soil:

Soil was collected from Agriculture Research Campus fields (29.9038ºN, 77.9975ºE), Haridwar (Uttarakhand) India. The site has a mean annual rainfall of 2136.7 mm and a mean annual air temperature of 10ºC to 38.9ºC. This soil was classified as sandy loam. Soil samples were brought to the laboratory, air-dried and passed through a 2-mm sieve and analysed. The soil was alkaline, low in organic carbon content and in available macronutrients (N, P, K). Available micronutrients (Cu, Zn, Mn, Fe) were present in sufficient amount (Table 1).

TABLE 1
PHYSICO-CHEMICAL PROPERTIES OF SOIL

S.No.	Parameter	Values
1	pH	8.4±0.00
2	Electrical conductivity (dS/m)	0.4±0.00
3	Organic Carbon (%)	0.3±0.01
4	Available Potassium (kg ha^{-1})	59.9±1.82
5	Available Phosphorus (kg ha^{-1})	11.0±0.11
6	Available Sulphur (kg ha^{-1})	23.1±1.44
7	Available Nitrogen (kg ha^{-1})	243.9±0.88
8	Iron (ppm)	12.1±0.14
9	Zinc (ppm)	1.9±0.07
10	Manganese (ppm)	6.8±0.12
11	Copper (ppm)	0.8±0.40

Values represent mean of triplicates, ±represents standard deviation

2.2 Ash production:

Yagya was performed by burning of cow dung (288g), cow butter (141 mL), Homa samagri - a medicinal herbal mixture (224g), unpolished rice in copper vessel known as Hawan kund with chanting of mantra. 65g Yagya ash was obtained after the burning of the content. Likewise, conventional wood ash was also collected from a boiler that used wood collected from nearby area.

2.3 Experimental trials:

2.3.1 Incubation experiments:

Yagya ash and wood ash were incubated in soil for 112 days at natural environmental conditions. Plastic pots were used for the study and 5 kg soil was filled in each pot. Experiment comprised of 15 treatments with Yagya ash and wood ash *i.e.* control (soil without amendment) and soils treated with ashes at different doses including 0.5, 1.0, 1.5, 2.0, 2.5, 5.0 and 10 g/kg soil. Two replicates for every treatment were prepared. Soil sampling was done at 0, 7, 14, 21, 28, 42, 56 and 112 days of incubation. To determine the changes on ash surfaces during the incubation, a different setup was used in disposable plastic cups of 150 ml capacity. These cups were filled with 98 g of dry soil and 2 g of ash. The ash particles were sandwiched between two sheets of nylon mesh (25-µm mesh size) and two equal layers of soil. The ash samples were spread over the nylon mesh with care to ensure maximum soil interaction and to allow the passage of air, soil solution and microbial communities. The 2 ash treatments were replicated twice and prepared separately for collecting ash samples after 112 days of incubation. All the pots were subsequently irrigated with distilled water to maintain 60% of the maximum water holding capacity. Subsamples from the pots were collected to measure available nutrients. Incubated ashes were separated from the disposable plastic pots, homogenized and dried before further surface analysis.

Experimental design

Yagya ash		Wood ash	
Treatments	**Details**	**Treatments**	**Details**
C1	Soil		
YA1	0.5 g/kg Yagya ash + soil	WA1	0.5 g/kg wood ash + soil
YA2	1 g/kg Yagya ash + soil	WA2	1 g/kg wood ash + soil
YA3	1.5 g/kg Yagya ash + soil	WA3	1.5 g/kg wood ash + soil
YA4	2 g/kg Yagya ash + soil	WA4	2 g/kg wood ash + soil
YA5	2.5 g/kg Yagya ash + soil	WA5	2.5 g/kg wood ash + soil
YA6	5 g/kg Yagya ash + soil	WA6	5 g/kg wood ash + soil
YA7	10 g/kg Yagya ash + soil	WA7	10 g/kg wood ash + soil

2.3.2 Pot experiments:

Pot trials were conducted with optimized ash dose obtained by the incubation experiments to investigate the effect of Yagya ash on pea crop. Total nine Treatments with Yagya ash and wood ash including control (C) was with soil only, organic fertilizer (C1), chemical fertilizers (C2), T1 (Yagya ash), T2 (Wood ash), T3 (Yagya ash + organic), T4 (Wood ash + organic), T5 (Yagya ash + chemical) and T6 (Wood ash + chemical) were conducted. Five pea seeds were sown in each pot containing 7 kg soil. Irrigation was done with tap water. Plants were harvested at 90 DAS for crop phenological analysis.

2.4 Analysis of soil and ash:

The pH and Electrical conductivity of soil and ash samples were measured using solid to distilled water ratios of 1:2 and 1:5, respectively. Soil organic carbon (%) was estimated according to the method given by Walkley and Black [11]. Available nitrogen (N), phosphorus (P), potassium (K), sulphur (S) and micronutrients (Cu, Mn, Zn and Fe) in soil was determined according to the methods given by Subbiah and Asija [12], Olsen [13], Merwin and Peech [14], Chesnin and Yien [15] and Lindsay and Norvell [16]. Likewise, total N in ash samples was determined by Kjeldahl method and total P, K, Cu, Mn, Fe and Zn in ash was digested with di-acid mixture HNO_3-$HClO_4$ and analysed further.

2.5 Soil and ash characterization:

2.5.1 FTIR:

Fourier transform infrared spectroscopy (FTIR) analysis was conducted on a PerkinElmer spectrum two spectrophotometer with an attenuated total reflectance (ATR). All the raw and soil incubated ash samples were dried, homogenized and sieved before the analysis. FTIR spectra from 16 scans were recorded in the wavenumber ranged 4000-400 cm^{-1} with a 4-cm^{-1} resolution.

2.5.2 SEM and EDS:

To assess the morphological and chemical compositional changes on ash surfaces during the incubation in soil, scanning electron microscopy-energy dispersive spectroscopy (SEM-EDS) was executed with Flex SEM 1000 (Hitachi). Dried ash samples were coated with the gold dust and were observed under the scanning electron microscope. Every ash sample was examined in multiple areas and locations.

2.6 Plant growth and yield:

2.6.1 Seed germination %:

Seed germination (%) was determined according to the following formula:

$$\text{Seed germination (\%)} = \frac{\text{Number of seeds germinated}}{\text{Number of seeds sown}} \times 100 \quad (1)$$

2.6.2 Phenological observations:

Different phenological characteristics like plant length, plant fresh biomass, nodes, number of nodules, number of pods/plants, and pod length were evaluated. Using a ruler, the length of the shoot and roots was measured in fresh plants from the point closest to the soil's surface to the longest part of the plant tip at maturity. For dry weight, the plant material was oven dried at 70ºC for 48 hours and weighed by using weighing balance.

2.7 Statistics:

Two-way analysis of variance (ANOVA) was conducted by Graphpad prism (version 10.0) to investigate the differences among the treatments.

III. RESULTS AND DISCUSSION

3.1 Characterization of the Yagya ash and wood ash:

The characteristic of Yagya ash and wood ash produced are given in Table 2. Both the ashes had an alkaline pH. Electrical conductivity was higher for wood ash (71.8±0.1) as compared to the Yagya ash (63.8±0.7). Higher content of organic carbon (1.8%), phosphorus (1.2%), potassium (5.2%), sulphur (0.6%), copper (125.3 ppm), manganese (588.7 ppm), zinc (154.4 ppm) and iron (801.7 ppm) was found in Yagya ash as compared to the wood ash. However, Heavy metal content such as cadmium, lead and nickel was higher by 54.9%, 87.1% and 29.1% in wood ash as compared to the Yagya ash. Several previous studies confirmed wood ash as an effective soil improvement material [17]. From the analysis results, it is clear that Yagya ash contains higher amount of plant essential nutrients and could be used as a soil fertilizer and soil conditioner in a better way than wood ash.

TABLE 2
CHARACTERIZATION OF YAGYA ASH AND WOOD ASH USED IN THE STUDY

S.No.	Parameters	Yagya ash	Wood ash
1	pH	11.8±0.17	13.2±0.01
2	Electrical conductivity (dS/m)	63.8±0.65	71.8±0.09
3	Organic Carbon (%)	1.8±0.57	0.4±0.11
4	Total Potassium (%)	5.2±0.69	4.3±0.07
5	Total Phosphorus (%)	1.2±0.03	0.9±0.01
6	Total Sulphur (%)	0.6±0.11	0.2±0.02
7	Total Nitrogen (%)	ND	ND
8	Calcium (%)	8.9±0.06	39.0±0.08
9	Iron (ppm)	801.7±0.58	786.9±0.16
10	Zinc (ppm)	154.4±0.07	52.5±0.23
11	Manganese (ppm)	588.7±0.80	866.4±0.44
12	Copper (ppm)	125.3±0.53	77.4±0.18
13	Cadmium (ppm)	3.7±0.63	8.2±0.15
14	Lead (ppm)	3.3±0.58	25.5±0.71
15	Nickel (ppm)	38.30.58	54.0±0.00

ND = Not Detected, ± denoted standard deviation among the duplicates and triplicates

3.2 Effect of Yagya ash on soil properties:

3.2.1 pH and EC:

The influence of Yagya ash and wood ash on soil pH is given in Figure 1a. On 7th day of incubation soil pH ranged from 8.5 to 8.6 and 8.5 to 8.7 in Yagya ash and wood ash treatments. The soil pH was increased with increase in ash concentration, 0.2 pH unit in Yagya ash treatments (YA7) and 0.3 pH units in wood ash treatments (WA7) @ 10g/kg soil as compared to the control. Wood ash caused more increase in pH as compared to the Yagya ash. Similar, findings reported increased pH with increased ash concentration are reported in some earlier studies [18, 19, 20, 21]. Interestingly, both the ash treatments caused an increase in soil pH for the first seven days. After 7th day of incubation, all treatments exhibited a declining trend in soil pH and on 112th day of incubation pH ranged from 5.8 to 7.6 and 7.7 to 8.2 in Yagya ash and wood ash treatments. The results are in accordance with Błońska et al. (2023), reported an increased soil pH over a short period of time on application of wood ash and the impact was more pronounced with increased dose. According to Ulery et al. [22] this is because the hydroxides, oxides and carbonates of potassium and sodium which are mainly responsible for increasing pH are highly soluble and do not remain in the soil for extended periods of time. In Yagya ash treatments, after incubation period of 112 days soils attain neutral pH. One possible reason behind this could be the presence of more decomposable matter in agnihotra ash as evident from organic carbon content (1.8%). Microorganisms can easily decompose those small organic molecules and produce CO_2, organic acids and ammonium ions and eventually reduce the soil pH. However, in wood ash treatments, pH of soil was declined at 112th day of incubation but not to greater extent and neutral pH was not attained. In treatment WA4, WA5, WA6 and WA7 the pH of soil was higher *i.e.* 8.2 at the end of incubation study, which could be harmful to plant growth, especially for species that can't withstand high pH [21]. Increase in soil pH on application of wood ash results due to the ligand exchange between SO_4 and OH ions [23].

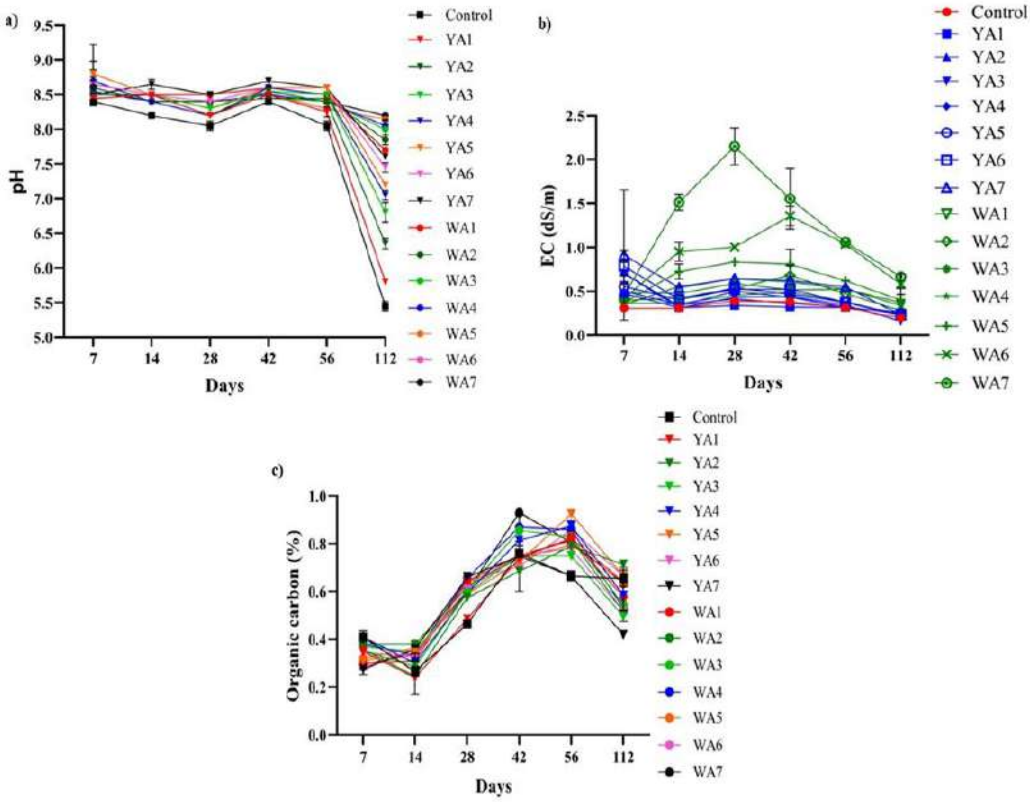

FIGURE 1: Effect of Yagya ash and wood ash on soil a) pH, b) Electrical conductivity and c) Organic carbon %

The influence of Yagya ash and wood ash on soil electrical conductivity (EC) is given in Figure 1b. Soil EC (dS/m) ranged from 0.5 to 0.9 and 0.4 to 2.2 in Yagya ash and wood ash treatments. EC was increased with increase in Yagya ash and wood ash dose in the soil. Similar increase in soil EC was previously reported by An and Park (2021) on application of wood ash. EC of soil treated with Yagya ash was increased till 7th day of incubation and a decline in EC was observed after it. In wood ash treatments, EC was increased till 28th day of incubation and after that a decline in EC was achieved. In Treatment WA7 soil EC was increased to 2.2 dS/m on 28th day of incubation. However, for plant health, EC should not surpass the threshold value of 2 dS/m (Herrero and Pérez-Coveta, 2005), a limit that was not surpassed by rest of the treatments. Though at the end of the incubation study *i.e.* at 112 days all Yagya ash (≤0.2 dS/m) and wood ash (0.2 to 0.7 dS/m) treatments had electrical conductivity of less than 0.50 dS/m, meaning that it did not surpass safety limits except WA6 and WA7. Similar trend in soil EC was reported by Surin et al. [24] in an incubation study with organic fertilizers in paddy soils.

3.2.2 Soil organic carbon %:

The soil organic carbon (%) content in treatments is given in Figure 1c. The organic carbon percent was decreased in all the treatments for first 14 days as compared to the control. OC% was increased after 14th day incubation study till 56th day of incubation with increase in ash concentration and follow the trend of decrease after this. Maximum organic carbon was observed in YA5 and WA6 0.93% and 1.05% treatments on 56th day and 42nd day of incubation respectively. In Yagya ash treatments peak was achieved on 56th day of incubation whereas, in wood ash treatments peak was achieved on 42nd day in treatments (WA4-WA7) and on 56th day of incubation in treatments (WA1-WA3). In all the treatments, ash application was able to improve the organic carbon content of soil. The results are comparable to a recent study by Błońska et al. [27]. Earlier studies have reported that application of wood ash to the soil resulted in carbon having high surface area and high metal oxides contents that can help organic residues to raise C amount in the soil [25, 26].

3.2.3 Soil available macronutrients (N, P, K):

The nitrogen release pattern in different treatments is given in Figure 2a. The results of the whole incubation period indicated that ash treatments are not able to release the sufficient amount of available nitrogen. The findings are comparable to those reported by Błońska et al. [27] and An and Park [21], confirmed the application of wood ash alone might not be sufficient option to compensate N deficiency. Available nitrogen content of soil was observed to be increased with incubation time till 28th day for Yagya ash treatments and till 42nd day of incubation for wood ash treatments.

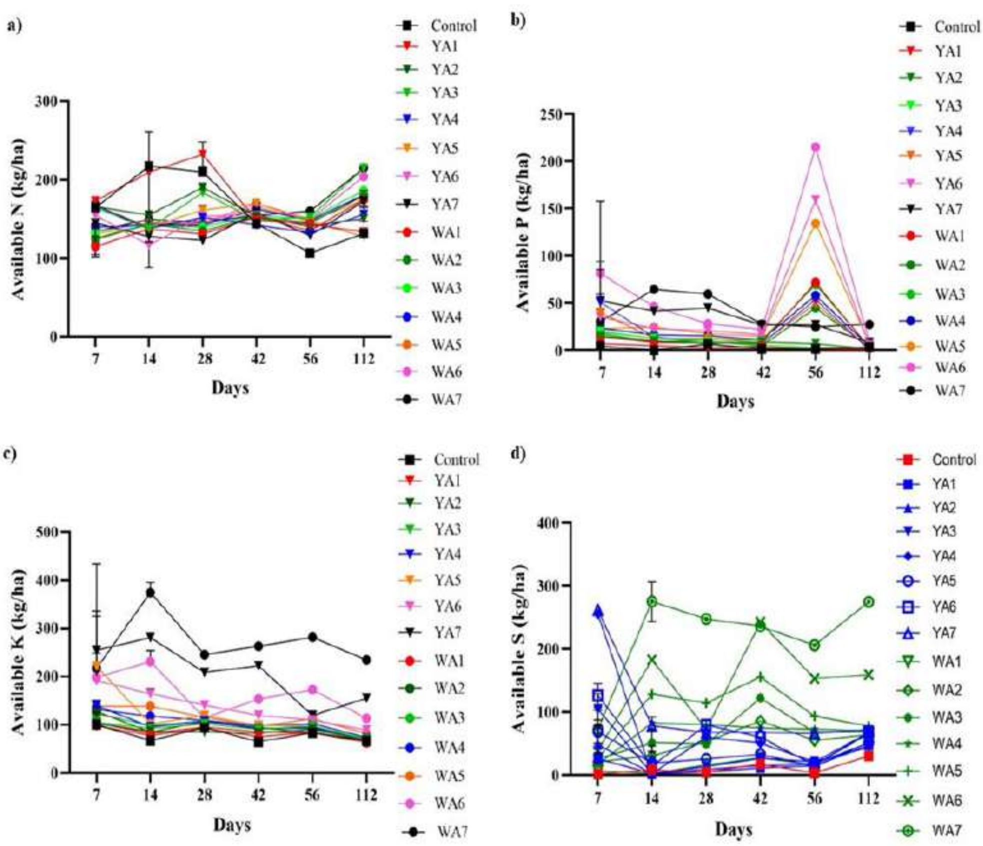

FIGURE 2: Effect of Yagya ash and wood ash on soil nutrients a) Available Nitrogen, b) Available phosphorus c) Available potassium and d) Available sulphur

The phosphorus release pattern in different treatments is given in Figure 2b. When ash treatments were applied to the sandy loam soil, all the ash concentrations released abundant phosphorus except YA1. Available phosphorus content was increased as the concentration of ash increased in both Yagya ash and wood ash treatments. Figure 2b shows a substantial P release by the treatments immediately after application and peak was achieved on 56th day of incubation and later after, all the treatments illustrated a similar diminishing trend. Maximum available P was observed in treatment YA6 and WA6 with 159.04 and 215.04 kg/ha. Likewise, the availability of potassium increased in soil with increase in ash concentration and peak (280.8 kg/ha, 374.6 kg/ha) was achieved on 14th day of incubation in both Yagya and wood ash treatments at concentration of 10g/kg of soil. After 14th day a declined trend was observed in all the treatments. Similar findings were reported in some recent studies [28,21,29].

3.2.4 Soil available sulphur:

Yagya and wood ash were able to supply sufficient amount of sulphur at all the concentrations. The results are comparable with those reported by Baloch et al. [29]. Available sulphur content was increased with increase in concentration. A peak (26.14 to 261.8 kg/ha) was achieved at 7th day of incubation in Yagya ash treatments with 14.1 to 140.8-fold increase in available S as compared to control. In wood ash treatments a peak was achieved at 14th day of incubation with 3.8 to 33.3-fold increase in available S in WA2-WA7 treatments. However, in wood ash treatments WA1 at concentration 0.5g/kg was not able to supply sufficient available S. After peak, a diminished trend was followed in all the treatments.

3.2.5 Soil available micronutrients:

The influence of Yagya and wood ash application on soil available micronutrients is shown in Figure 3. Available copper was increased with increase in ash concentration in both Yagya and wood ash treatments. Peak was observed in treatment YA7 (3.19 ppm) and WA7 (2.05 ppm) at 7th day of incubation. A decrease in copper content was observed after 7th day of incubation in all treatments. All treatments were able to supply sufficient amount of available copper to the soil. The availability of iron and manganese was decreased in all ash treatments as compared to the control (Figure 3c, d). All ash treatments were able to supply sufficient amount of iron except treatment WA1 and WA2. Available iron content was observed to increase till 28th day of incubation and then a diminished trend was followed. The findings are in accordance with Quirantes et al. [30] also reported no change in soil DTPA Fe and Mn on application of different ashes. This might be possible due to soil's hight content of DTPA Fe and Mn [31]. Similarly, the available zinc content was observed to increase with increase in dose in Yagya ash treatments. However, in case of wood ash treatments the Zn content was observed to be decreased in all concentrations. Peak was achieved at 7th day of incubation 1.39 ppm and 1.15 ppm for YA7 and WA1 and a diminished trend was followed after 7th day of incubation.

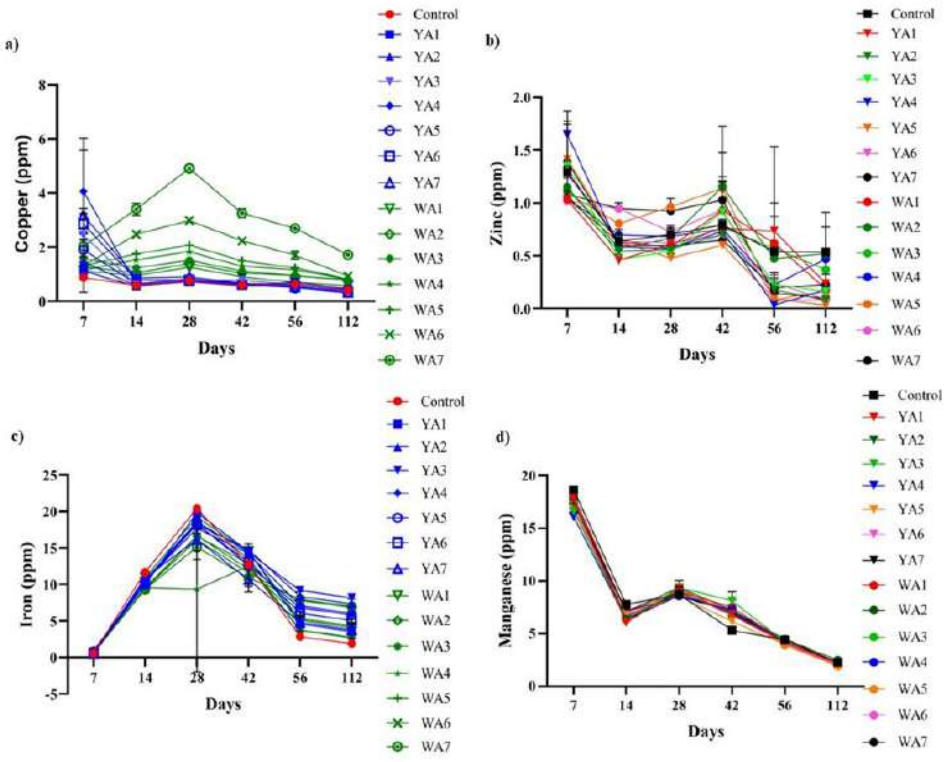

FIGURE 3: Effect of Yagya ash and wood ash on soil micronutrients a) Copper, b) Zinc, c) Iron and d) Manganese

3.3 Changes in ash surface functional groups (FTIR analysis):

The Fourier Transform Infrared Spectroscopy (FTIR) spectra of Yagya ash and wood ash showed numerous peaks between 1460 to 420 cm^{1} (Figure 4a). Peaks in Yagya ash obtained before incubation were 1455, 1035,615, 564, 435 cm^{1} and after incubation were 1415, 1045, 865, 710, 420 cm^{1} respectively. Likewise, for wood ash the peaks were at 1460, 1009, 595, 555 and 435 cm^{1} before incubation and after incubation the peaks were at 1410, 1025, 870, 705, 569, 445 cm^{1}. The absorption peaks in Yagya and wood ash before incubation were showed the functional groups carboxylic acids, alkenes and alcohols. After incubation the peaks represent carboxylic acids, aromatic hydrocarbons and alcohols.

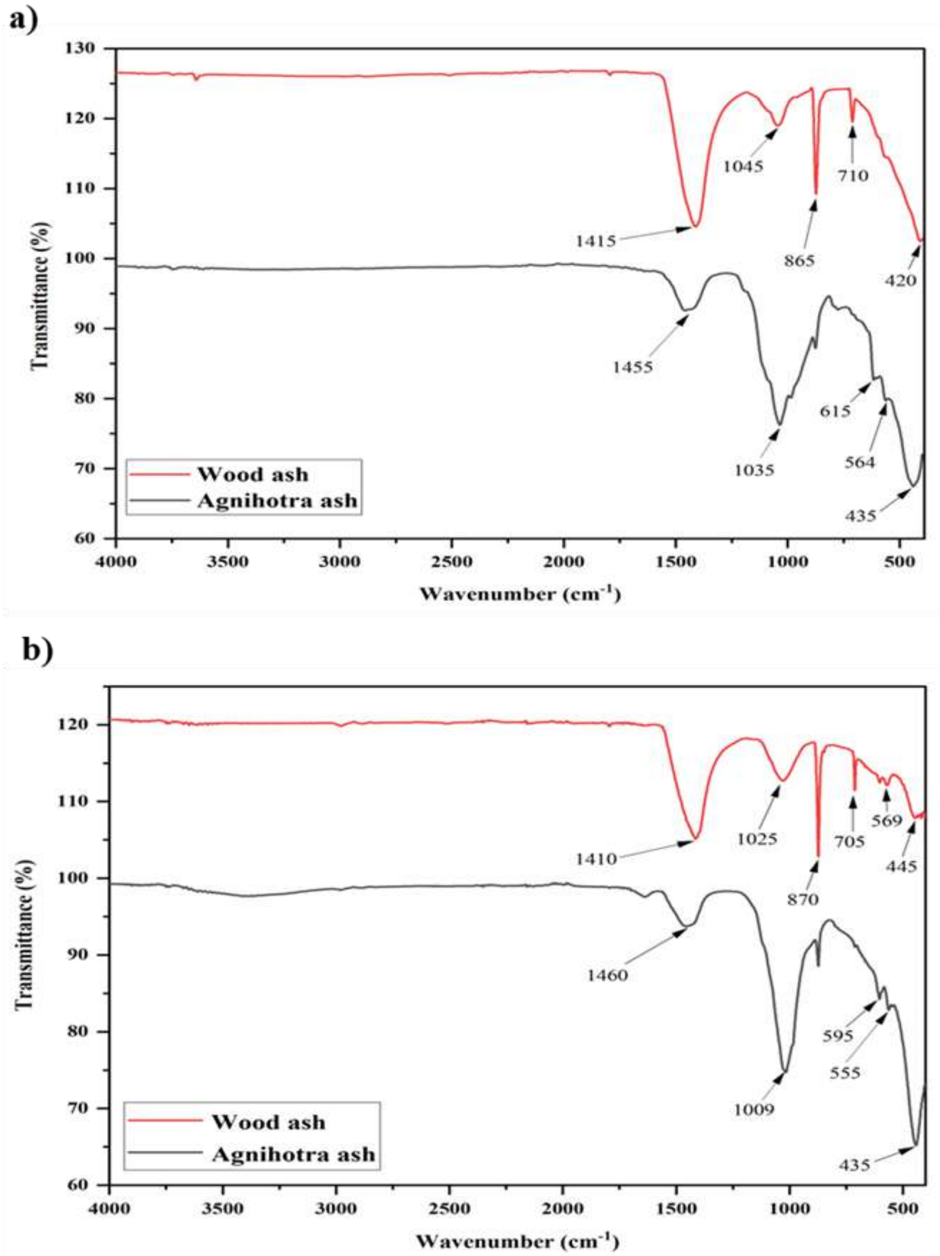

FIGURE 4: FTIR spectra of Yagya (Agnihotra) ash and wood ash a) before incubation and b) after incubation

3.4 Changes in ash surface morphology and elemental composition (SEM-EDS):

The SEM photographs of Yagya ash or agnihotra ash (before and after incubation) and wood ash are depicted in Figure 5. All the ash samples were having in-homogeneous particle sizes and ranged from sub-micron to few microns. Yagya and wood ash particles ranged from 1.24 µm to 21.9 µm, 1.6 µm to 31.2 µm, respectively. From the figure, it is clear that ash particles of both Yagya ash and wood ash were present in aggregated before the incubation study. Generally, no significant changes were observed between the surface morphologies of the ash samples before and after incubation. After incubation the ash aggregate particles were dissolved and separated in small particles. Soil clay particles were observed in the ash samples after the incubation. From EDS micrographs, it is clear that Yagya ash contains elements in higher amount as compared to the wood ash. After incubation, reduction in the content of elements was observed.

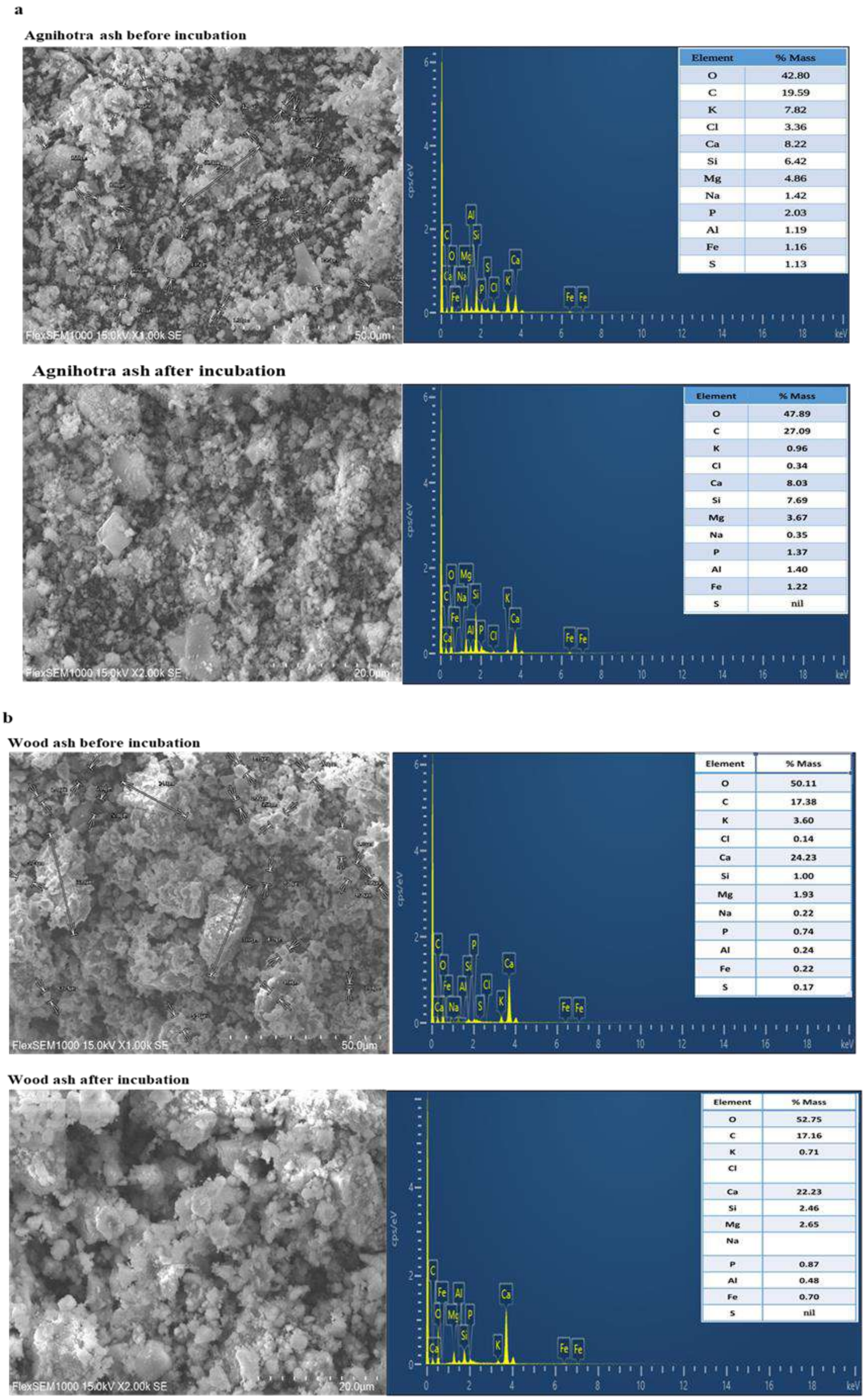

FIGURE 5: Scanning electron micrographs with energy dispersive X-ray spectroscopy a) Yagya (Agnihotra) ash and b) Wood ash before and after incubation

3.5 Effect of Yagya ash on crop phenology

Pea pot trials were conducted with Yagya ash and wood ash at concentration of 2g/kg soil, on the basis of results obtained in incubation study. The germination percent ranged from 53.3 to 73.3 treatments (Table 3). Maximum seed germination of 73.3% was achieved in T2 (wood ash), T3 (Yagya ash + organic) and T5 (Yagya ash + chemical) treatments. Several reports and studies suggest that Yagya ash can enhance seed germination. The minerals in the ash may provide the necessary nutrients for seeds to sprout more successfully. In some instances, it has been noted that seeds treated with Yagya ash exhibit higher germination rates compared to those untreated [32]. According to Singh and Sharma [33] improved soil health supports better water retention, aeration, and nutrient availability could be possible reason for improved seed germination.

The plant growth parameters such as plant length, plant biomass and nodules per plant were maximum with T5 (Yagya ash + chemical) treatment and maximum number of node/plant was observed with T6 (wood ash + chemical) treatment. The application of Yagya ash has been linked to increased crop yields in various studies. For instance, it has been shown to improve the growth of medicinal plants, vegetables and fruit crops [34]. It aids in stimulating root and shoot growth, resulting in healthier and more robust plants.

Yield parameters such as number of pods per plant and pod length was achieved maximum (8.3 and 9.37 cm) with C2 (chemical) treatment and T5 (Yagya ash + chemical) treatment.

TABLE 3
EFFECT OF YAGYA ASH AND WOOD ASH ON PLANT GROWTH

Seed germination and plant growth parameters							
Treatment	**Seed germination (%)**	**Plant Length (cm)**	**Plant Biomass (g)**	**No. of node/plant**	**Nodules**	**No. of pod/plant**	**Pod length (cm)**
C	60	72.5±0.38	16.1±0.69	13.5±0.71	16±0.00	4±0.00	8.8±0.29
C1	70.3	56.5±0.85	11.2±0.43	17±1.41	13.5±0.71	5.7±0.58	8.2±0.87
C2	66.7	68.35±0.97	17.4±0.43	19±1.41	15.5±0.71	8.3±1.15	8.9±0.23
T1	66.7	63.95±0.53	13.4±0.41	18.5±2.12	15.5±0.71	5.0±0.00	8.2±0.35
T2	73.3	62.3±0.49	15.6±0.55	20±1.41	19.5±0.71	5.0±0.00	8.8±0.36
T3	73.3	55.6±0.80	7.9±0.24	20.5±1.41	11.5±0.71	4.0±1.00	9.2±0.78
T4	53.3	67.1±0.62	14.1±0.37	20.5±0.71	13.5±0.00	6.3±0.58	8.8±0.21
T5	73.3	78.5±0.35	29.2±0.49	14±0.71	20±0.71	5.3±1.15	9.4±0.40
T6	60	64.8±0.36	13.0±0.21	22.5±0.71	14±0.00	4.7±1.15	9.3±0.58

TABLE 4
EFFECT OF YAGYA ASH AND WOOD ASH ON PLANT NUTRIENTS

Treatment	Nitrogen (%)	Phosphorus (%)	Potassium (%)	Sulphur (%)	Copper (%)	Zinc (%)	Manganese (%)	Iron (%)
C	0.21±0.02	0.43±0.00	1.86±0.11	0.89±0.14	10.65±0.05	40.6±0.24	33.96±1.99	229.0±2.60
C1	0.64±0.21	0.49±0.02	1.83±0.05	1.33±0.11	9.56±0.76	40.4±0.06	34.05±0.12	193.2±0.56
C2	0.98±0.01	0.42±0.01	1.89±0.02	1.62±0.11	9.82±0.62	42.4±0.29	38.14±0.28	298.2±0.35
T1	0.20±0.13	0.39±0.01	2.13±0.09	1.92±0.16	9.09±1.02	37.1±0.74	35.61±0.49	388.4±0.82
T2	0.36±0.25	0.29±0.01	1.99±0.03	2.05±0.13	8.98±1.10	35.2±1.26	31.26±1.26	268.3±2.88
T3	2.12±0.02	0.32±0.00	1.85±0.05	2.25±0.07	10.03±0.21	48.4±0.98	35.61±0.04	256.0±1.15
T4	0.54±0.57	0.39±0.01	2.07±0.06	2.37±0.06	9.56±0.35	40.8±0.83	39.64±1.15	213.3±1.05
T5	1.74±0.02	0.32±0.01	2.02±0.05	2.66±0.05	11.18±0.00	39.0±1.11	41.15±1.60	186.0±1.06
T6	1.75±0.30	0.38±0.01	2.09±0.14	2.51±0.02	10.54±0.81	39.6±0.04	36.49±1.03	107.1±0.37

± represents standard deviation among the duplicates and triplicates
(C-Control, C1-Organic, C2-Chemical, T1-Yagya ash, T2-wood ash, T3-Yagya ash+organic, T4-Wood ash+organic, T5-Yagya ash +chemical, T6-Wood ash+chemical)

Impact of different treatments on plant nutrients is summarized in Table 4. From the table, it is evident that application of Yagya ash with both organic and inorganic inputs improved the plant nutrients. Maximum potassium and iron content was achieved in T1 (Yagya ash) treatment. Maximum nitrogen and zinc content was observed in treatment T3 (Yagya ash+organic). Maximum sulphur and manganese content was achieved with treatment T5 (Yagya ash + chemical). Maximum phosphorus content was achieved in C1 treatment (organic).

IV. CONCLUSION

The present study suggest that the ash derived from Yagya positively affects soil fertility, seed germination, plant growth, yield and quality of produce. pH and electrical conductivity of the soil increased in all treatments initially but normalized at the end of the incubation in Yagya ash. In this way, Yagya ash supplies all plant essential nutrients including P, K, S Cu, and Zn without increasing pH and EC of soil. Moreover, application of Yagya ash with both organic and inorganic inputs improved the seed germination, plant growth parameters and plant nutrients. From the results, it is clear that Yagya ash contains higher amount of plant essential nutrients and in moderate dose could be used as a soil fertilizer and soil conditioner in a better way than wood ash and could be used as a booster for organic fertilizers and substitute to the inorganic fertilizers. This study also bridges traditional knowledge and modern science, providing a foundation for further research into agricultural application of Yagya and Yagya ash and more studies should be conducted to explore the effect of Yagya ash on soil microbes and enzymes to elucidate the mechanism lies behind.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

REFERENCES

[1] Tilman, D., Cassman, K.G., Matson, P.A., Naylor, R., Polasky, S., 2002. Agricultural sustainability and intensive production practices. Nature. 418, 671-677.

[2] Vitousek, P.M., Naylor, R., Crews, T., David, M., Drinkwater, L., Holland, E., Johnes, P., Katzenberger, J., Martinelli, L., Matson, P., 2009. Nutrient imbalances in agricultural development. Science. 324, 1519-1520.

[3] Arden-Clarke, C., Hodges, R., 1988. The environmental effects of conventional and organic/biological farming systems. II. Soil ecology, soil fertility and nutrient cycles. Biol Agric Hortic. 5, 223-287.

[4] Cronan, C.S., Grigal, D.F., 1995. Use of calcium/aluminium ratios as indicators of stress in forest ecosystems. J Environ Qual. 24, 209-226.

[5] Saarsalmi, A., Mälkönen, E., Kukkola, M., 2004. Effect of wood ash fertilization on soil chemical properties and stand nutrient status and growth of some coniferous stands in Finland Scand J For Res. 19, 217-233.

[6] Augusto, L., Bakker, M.R., Meredieu, C., 2008. Wood ash applications to temperate forest ecosystems - Potential benefits and drawbacks. Plant Soil. 306, 181-198.

[7] Perkiömäki, J., Fritze, H., 2002. Short and long-term effects of wood ash on the boreal forest humus microbial community. Soil Biol Biochem. 34, 1343-1353.

[8] Pugliese, S., Jones, T., Preston, M.D., Hazlett, P., Tran, H., Basiliko, N., 2014. Wood ash as a forest soil amendment: The role of boiler and soil type on soil property response. Can J Soil Sci. 94, 621- 634.

[9] Saarsalmi, A., Smolander, A., Kukkola, M., Arola, M., 2010. Effect of wood ash and nitrogen fertilization on soil chemical properties, soil microbial processes, and stand growth in two coniferous stands in Finland. Plant Soil. 331, 329-340.

[10] Johansen, J.L., Nielsen, M.L., Vestergård, M., Mortensen, H., Cruz-Paredes, C., Rønn, R., Ekelund, F., 2021. The complexity of wood ash fertilization disentangled: Effects on soil pH, nutrient status, plant growth and cadmium accumulation. Environ Exp Bot. 185, 104424.

[11] Walkley, A., Black, I.A., 1934. An examination of Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Sci. 37, 29-37.

[12] Subbiah, B.V., Asija, G.L., 1956. A rapid procedure for the determination of available nitrogen in soil. Curr Sci. 25, 259-260.

[13] Olsen, S., Cole, C., Watanabe, F., Dean, L., 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. USDA Circular Nr 939, US Government Print Office, Washington, D.C.

[14] Merwin, H.D., Peech, M., 1950. Exchangeability of soil potassium in the sand, silt and clay fractions as influenced by the nature of the complimentary exchangeable cations. Soil Sci Soc Amer Proc.15,125-28.

[15] Chesnin, L., Yen, C.H., 1950. Turbidimetric determination of available sulphates. Soil Sci Soc Amer.15, 149-151.

[16] Lindsay, W.L., Norvell, W.A., 1978 Development of a DTPA soil test for zinc, iron, manganese, and copper. Soil Sci Soc Amer. 42, 421-428.

[17] Demeyer, A., Voundi, Nakana, J.C., Verloo, M.G., 2001. Characteristics of wood ash and influence on soil properties and nutrient uptake: an overview. Bioresour Technol. 77, 287-295.

[18] Ohno, T., Erich, M.S., 1990. Effect of wood ash application on soil pH and soil test nutrient levels. Agric Ecosyst Environ. 32, 223-239.

[19] Voundi Nkana, J.C., Demeyer, A., Verloo, M.G., 2002. Effect of wood ash application on soil solution chemistry of tropical acid soils: incubation study. Bioresour Technol. 85, 323-325.

[20] Bang-Andreasen, T., Nielsen, J.T., Voriskova, J., Heise, J., Rønn, R., Kjøller, R., Hansen, H.C.B., Jacobsen, C.S., 2017. Wood Ash Induced pH Changes Strongly Affect Soil Bacterial Numbers and Community Composition. Fron Microbiol. 8,1400.

[21] An, J.Y., Park, B.B., 2021. Effects of wood ash and N fertilization on soil chemical properties and growth of *Zelkova serrata* across soil types. Sci Rep. 11, 14489.

[22] Ulery, A.L., Graham, R.C., Amrhein, C., 1993. Wood-ash composition and soil pH following intense burning. Soil Sci. 156, 358- 364.

[23] Alva, A.K., Sumner, M.E., 1990. Amelioration of acid soil infertility by phosphogypsum. Plant Soil. 128, 127-134.

[24] Herrero, J., Pérez-Coveta, O., 2005. Soil salinity changes over 24 years in a Mediterranean irrigated district. Geoderma. 125, 287-308.

[25] Surin, P., Supsuan, P., Yampracha, S., 2019. Release of various elements from organic fertilizers incubated in organic and non-organic paddy soils at various time periods. Curr Appl Sci Technol. 19, 276-288.

[26] Reed, E.Y., Chadwick, D.R., Hill, P.W., Jone, D.L., 2017. Critical comparison of the impact of biochar and wood ash on soil organic matter cycling and grassland productivity. Soil Biol Biochem. 110, 134-142.

[27] Muhammad, I., Wang, J., Sainju, U.M., Zhang, S., Zhao, F., Khan, A., 2021. Cover cropping enhances soil microbial biomass and affects microbial community structure: a meta-analysis. Geoderma. 381, 114696.

[28] Błońska, E., Prażuch, W., Boroń, P., Lasota, J., 2023. Effects of wood ash on the soil properties and fungal community structure in a beech forest in Poland. Geoderma Reg. l34, e00676.

[29] Jansone, B., Samariks, V., Okmanis, M., Klavina, D., Lazdin, D., 2020. Effect of high concentrations of wood ash on soil properties and development of young norway Spruce (*Picea abies* (L.) Karst) and Scots Pine (*Pinus sylvestris* L.). Sustainability. 12, 9479.

[30] Baloch, S.B., Ali, S., Bernas, J., Moudrý, J., Konvalina, P.,Mushtaq, Z., Murindangabo, Y.T.,Onyebuch, E.Z., Baloch, F.B., Ahmad, M., Saeed, Q., Mustafa, A., 2024. Wood ash application for crop production, amelioration of soil acidity and contaminated environments. Chemosphere. 357, 141865.

[31] Quirantes, M., Calvo, F., Romero, E., Nogales, R., 2016. Soil-nutrient availability affected by different biomass-ash applications. J Soil Sci Plant Nutr. 16, 159-163.

[32] Soltanpour, P.N., 1985. Use of ammonium bicarbonate DTPA soil test to evaluate elemental availability and toxicity. Commun Soil Sci Plan. 16, 323- 338.

[33] Kumar, V., Tiwari, R., 2002. The role of Agnihotra ash in soil fertility and seed germination. J Agric Sci. 14, 101-107.

[34] Singh, R., Sharm,a D., 2015. Agricultural Benefits of Agnihotra Ash: Effects on Seed Germination and Plant Growth. Int J Agric Res. 10, 45-53.

[35] Choudhury, P., Mishra, R., 2015. Influence of Agnihotra Ash on Growth of Medicinal Plants. J Hortic Sci. 49, 304-310.

Harnessing Municipal Solid Waste: Enzymatic Pathways to Bioethanol Sustainability: A Review

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Abstract— *Waste management problems and the need for renewable energy can be addressed by utilizing municipal solid waste for bioethanol production as a renewable feedstock. The enzymatic hydrolysis process of turning solid waste into fermentable sugars for the subsequent production of bioethanol is the main focus of the current study. Enzyme access is significantly facilitated by effective pretreatment, particularly the alkali process with NaOH, which breaks the resistant lignocellulosic structure. Hydrolysis is possible under moderate circumstances (40–50°C, pH 4.5–5.0) thanks to fungal-derived cellulolytic enzymes from Aspergillus and Trichoderma strains. Using ethanologenic yeasts such as Saccharomyces cerevisiae and Pichia stipitis, the sugar-containing hydrolysate is then fermented, with optimised procedures producing ethanol. It has been discovered that integration approaches to the process, like simultaneous fermentation and saccharification, increase efficiency compared to independent operating steps. Despite promising results, problems with process optimisation, biomass recalcitrance, and enzyme cost persist. Enzymatic hydrolysis is used in this study as an example of a possible method for turning municipal waste into bioethanol; however, further technological advancements are required to increase the economic feasibility and commercial use of this environmentally friendly bioconversion process.*

Keywords— lignocellulosic, fermentation, recalcitrance, enzymatic hydrolysis, bioethanol, waste management, municipal solid waste, and pretreatment.

I. INTRODUCTION

Numerous studies on the production of bioethanol from lignin-based biomass, including solid waste from municipalities, have been spurred by the growing demand for renewable energy sources. MSW is a good feedstock for the production of bioethanol because it contains avast volume of organic waste, which is high in cellulose, hemicellulose, and lignin.(Kumar *et al.*2020 and Srivastava *et al.* 2017).Due to its many benefits over chemical hydrolysis methods, including high specificity, lower energy inputs, and environmentally friendly processing, enzymatic hydrolysis is an important step in the conversion of MSW to fermentable sugars. (Patra *et al.* 2017 and Banerjee *et al.* 2019). Alkaline, acidic, and steam explosion pretreatments are a few of the pretreatment techniques that have been employed to maximise the enzymatic hydrolysis efficiency of biomass derived from MSW. (Singh *et al.* 2019 and Chen *et al.* 2017).

One easily accessible and under-utilised resource that has become a promising option for the production of renewable biofuels is municipal solid waste. The accumulation of MSW has become a significant environmental issue due to global urbanisation, necessitating the development of environmentally friendly waste management solutions. Pollution and climate change are caused by conventional waste treatment methods like incineration and landfilling. The renewable energy production and the removal of environmental pollution are two benefits of using MSW as bioethanol through enzymatic hydrolysis. (Sharma *et* *al.* 2019). Furthermore, governments and research institutions worldwide have recognised the potential of waste-to-energy technologies and have been investing in the advancement of enzymatic hydrolysis and biomass pretreatment techniques (Lynd*et.al* 2017).

Hemicellulases and cellulases are essential for the hydrolysis process by enzymes because they break down structural carbohydrates into monomeric sugar, which microbes then ferment to produce ethanol.(Sarkar *et al. 2012* and Zhang *et al.* 2018)Recent developments in microbial fermentation, genetic engineering, and enzyme science have significantly increased the efficiency of producing bioethanol from MSW.(Gupta *et al.* 2020 and Singhania *et al.* 2013). While Taherzadeh *et al.* and Karimi *et al.* (2007) studied enzyme-based hydrolysis techniques, authors such as Lynd *et al.* and Wyman *et a*l. have contributed to the explanation of the enzymatic hydrolysis of complex polysaccharides to fermentable sugars. However, the main obstacles to scaling up this technology are problems like enzyme inhibition, restricted substrate accessibility, and higher production costs (Wyman *et al.* 2005and Banerjee *et al.* 2010).

Furthermore, studies by Zhang *et al.* 2018 and Lynd *et al.* 2017, and Sun *et al*. and Cheng *et al*. (2002) have demonstrated the impact of different pretreatment techniques on the efficiency of enzymatic hydrolysis. As a more sustainable alternative to chemical pretreatment, biological pretreatment such as microbial degradation via ligninolytic fungi has also been studied. The development of metabolic engineering of fermentative microorganisms is also noteworthy because, as Singhania *et al*.'s research shows, it has made it possible to produce more ethanol from mixed sugar substrates. The second crucial area of research is process optimisation, where it has been discovered that simultaneous saccharification and fermentation (SSF) increases ethanol yields by lowering process costs and end-product inhibition. (Miller *et al.*1959).

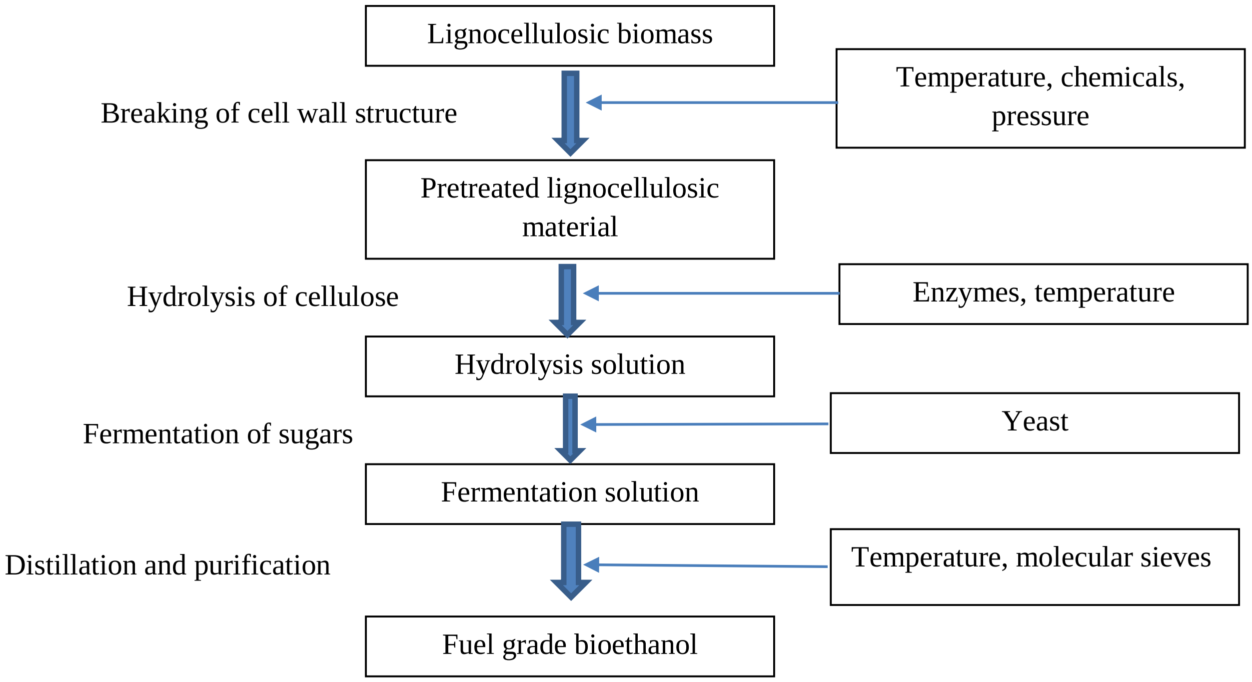

FIGURE 1: Schematic representation of the biomass conversion into bioethanol.

All things considered, the transition to using MSW for the production of bioethanol is a significant step towards a circular economy, in which waste is recycled to create beneficial biofuels. The recent developments in the enzymatic hydrolysis of MSW are examined in this review, with a focus on process integration, fermentation tactics, enzyme optimisation, and pretreatment methods for effective bioethanol production. This research aims to contribute to the ongoing efforts to make bioethanol a viable and scalable alternative to fossil fuels by addressing current issues and identifying potential technological advancements.

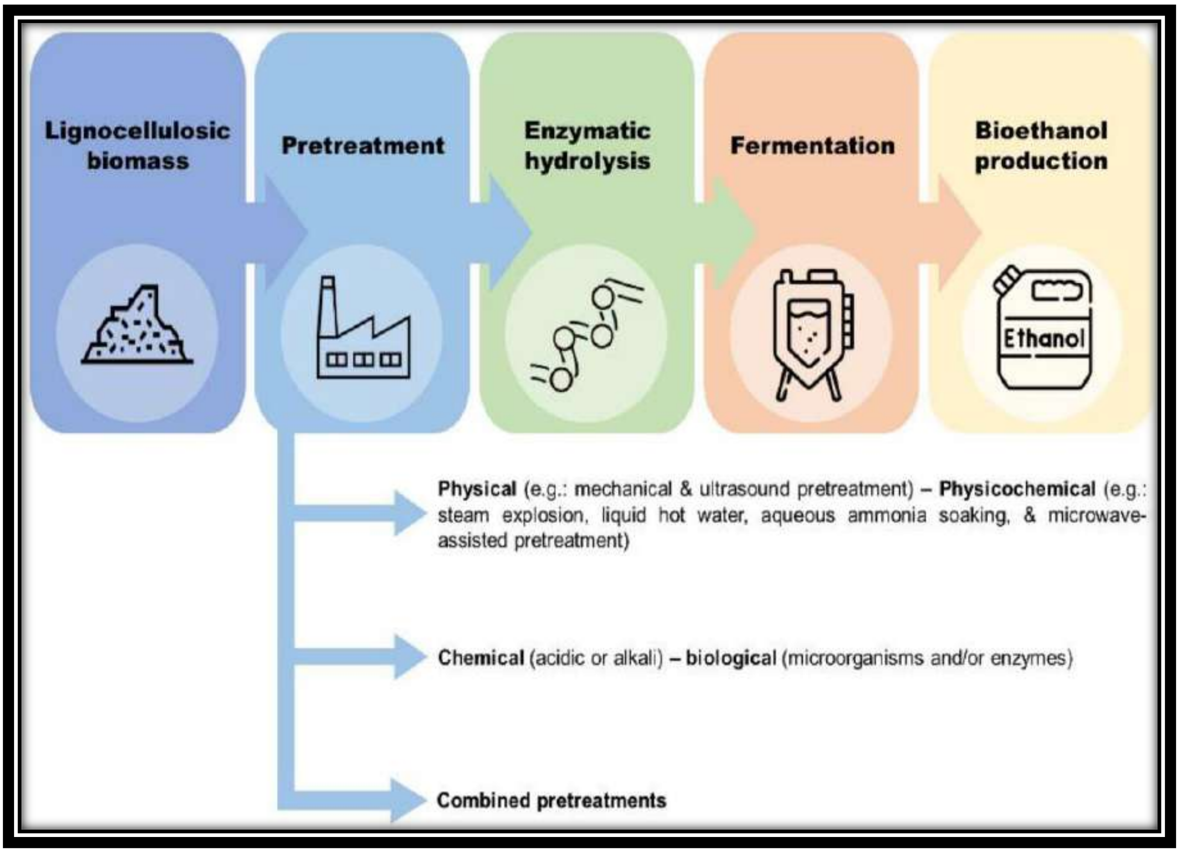

FIGURE 2: General overview of bioethanol production from lignocellulosic biomass.

II. MATERIALS AND METHODS

The significant amount of cellulose-containing waste materials, such as paper, cardboard, and food waste, MSW, was selected as the feedstock. (Sun *et al.* 2002 and Mood *et al.* 2013). The source and collection method affect the structure and content of MSW, which in turn affects how it is used for enzymatic hydrolysis (Taherzadeh *et al.* and Karimi *et al*. 2007, and Wyman *et al*. 2005). To determine MSW's suitability as a feedstock for the production of bioethanol, some studies have looked at its physicochemical characteristics**.** (Banerjee *et al.* 2010 and Jönsson *et al* 2016).

To break the resistant structure of the lignocellulosic compounds in MSW, pretreatment is required. To break down lignin and enhance enzyme access, alkaline hydrolysis using NaOH or ammonia was used (Kumar *et al.* 2020 and Mansfield *et al.*1999).

To hydrolyse hemicellulose and get rid of inhibitors, acid hydrolysis using diluted sulphuric or hydrochloric acid was done.(Hendriks *et al.* 2009 and Bansal *et al.* 2012). By upsetting the structure of the biomass, steam explosion, a high-pressure steam process was used to improve enzymatic digestibility. (Miller *et al.* 1959 and Chang *et al.* 2016) Furthermore, lignin and hemicellulose were preferentially broken down by biological pretreatment using microbial cultures or enzymes, increasing the accessibility of cellulose (Sun *et al.* 2002 and Mood *et al.* 2013).

Cellulose and hemicellulose were hydrolyzed to fermentable sugars by enzymatic hydrolysis using a combination of cellulases and hemicellulases.(Taherzadeh *et al*. 2007 and Wyman *et al.* 2005).Altering the enzyme concentration (5–20 FPU/g substrate), temperature (45–55°C), pH (4.8–5.5), reaction time (24–72 hours), and substrate loading (5–20% w/v) allowed for optimisation.(Banerjee *et al.* 2010 and Jönsson *et al* 2016). To improve hydrolysis efficiency, several enzyme cocktails were screened, such as ***Aspergillus niger*** hemicellulases and industrial cellulases from ***Trichoderma reesei***. (Kumar *et al.* 2020 and Mansfield *et al.*1999).

To evaluate enzyme stability and sugar recovery, hydrolysis was performed in batch and fed-batch operations. The process was made cost-effective by utilising enzyme recycling techniques, such as immobilisation and adsorption-desorption procedures (Hendriks *et al.* 2009 and Bansal *et al.* 2012).

Ethanogenic microorganisms such as ***Zymomonas mobilis, Saccharomyces cerevisiae***, or genetically modified ***Escherichia coli*** were used to ferment hydrolysed sugars (Hendriks *et al.* 2009 and Bansal *et al.* 2012). The highest ethanol production was attained by optimising fermentation parameters such as pH (4.5–6.0), temperature (30–37°C), agitation (100–200 rpm), and nutrient addition. (Miller *et al.* 1959 and Chang *et al.*2016). To compare them, process integration techniques like simultaneous saccharification and fermentation (SSF) and Separate hydrolysis and fermentation (SHF) were assessed. To increase the production of ethanol, the co-fermentation of pentose and hexose sugars was also investigated. (Sharma *et al*. 2019 and Gupta *et al*. 2020) To improve microbial resistance to inhibitors in hydrolysates, metabolic engineering techniques were applied (Mood *et al.* 2013 and Jönsson *et al* 2016). Reducing sugars, ethanol production, and biomass composition were measured in order to compare the efficiency of enzymatic hydrolysis and fermentation. The reducing sugar was measured using the Dinitrosalicylic Acid (DNSA) assay, which showed an increase from 250 mg/L to 750 mg/L after enzymatic hydrolysis (Miller *et al.* 1959). Depending on the fermentation conditions and substrate, yields of 30-45 g/L were reported using high-performance liquid chromatography (HPLC) to determine the ethanol content· (Zhang *et al.* 2018 and Singhania *et al.* 2013). Scanning electron microscopy (SEM) and Fourier-transform infrared spectroscopy (FTIR) were used to compare the structural changes made to MSW biomass before and after hydrolysis. (Mood *et al.* 2013 and Jönsson *et al* 2016). Furthermore, to predict hydrolysis performance and provide ideal enzymatic reaction parameters, kinetic modelling was carried out. (Taherzadeh *et al*. 2007 and Wyman *et al.* 2005).

III. RESULTS AND DISCUSSION

Under ideal circumstances, the lower sugar concentrations increased from the initial 200 mg/L to over 800 mg/L, resulting in a high sugar release from the enzymatic hydrolysis of MSW.(Kumar *et al.* 2020).The most effective pretreatment for maximising enzymatic digestibility was alkaline, which increased sugar yield by 45–60% compared to untreated MSW.(Srivastava *et al.* 2017)**.**Despite being effective at breaking down hemicellulose, acid hydrolysis created compounds that inhibited fermentation, such as furfural and hydroxymethylfurfural, which required detoxification processes.(Patra *et al.* 2017). The microbial strain and process parameters affected the fermentation efficiency. While SSF was more productive and showed less end-product inhibition, Saccharomyces cerevisiae produced 40 g/L of ethanol in SHF.(Banerjee *et al.* 2019).By effectively utilising pentose sugar, co-fermentation using modified *Escherichia coli* enhanced ethanol yield by 15–20%. Under ideal fermentation and enzyme loading conditions, the highest ethanol content was 45 g/L. (Chen *et al.* 2017). Following enzymatic hydrolysis, structural characterisation using FTIR and SEM demonstrated widespread degradation of lignocellulosic moieties, with cellulose's crystallinity being reduced by 30–50%, depending on the pretreatment.(Sharma *et al.*2019). According to kinetic studies, hydrolysis was a first-order reaction, and the rate of reaction increased as the enzyme dose increased. (Lynd *et al.* 2017).

Although encouraging progress has been made, large-scale realisation remains a challenge. Process economics are impacted by substrate heterogeneity and enzyme prices, which necessitate advancements in process integration and enzyme recycling (Sarkar *et al.* 2012). To improve hydrolysis and fermentation efficiency at a reduced cost, future efforts should focus on developing stable microbial strains and efficient enzyme formulations (Zhang *et al.* 2018). This study highlights the potential of enzymatic hydrolysis for the production of bioethanol from MSW, which has significantly improved ethanol productivity and sugar recovery through the use of microbial engineering techniques and optimised process conditions.

IV. CONCLUSION

One promising method for producing bioethanol sustainably is the enzymatic hydrolysis of MSW. The effectiveness of enzymatic hydrolysis and optimised pretreatment techniques in significantly increasing sugar recovery and ethanol yield is covered in this work. However, to make it appropriate for large-scale implementation, technical and financial challenges such as substrate heterogeneity, process scale-up, and enzyme cost must be resolved. To make it more effective and economical, future research should concentrate on developing enzyme engineering, optimising microbial fermentation, and integrating bioprocesses.

In addition to producing energy, waste management and bioethanol production can have two benefits: reducing landfill disposal and promoting the circular economy. Enhancing the economic feasibility of bioethanol production will require improvements in microbial strains, process technology, and enzyme recycling. To facilitate the transition to cleaner biofuels, governments and industry must collaborate in supporting research and development projects. If these obstacles are removed, enzymatic hydrolysis of MSW would contribute significantly to the attainment of global renewable energy goals, reduce reliance on fossil fuels, and reduce environmental pollution, all of which would contribute to a cleaner, more sustainable world.

REFERENCES

[1] Kumar, S., Singh, R., & Kumar, V. (2020). Optimization of enzymatic hydrolysis conditions for bioethanol production from municipal solid waste. *Bioresource Technology, 297*, 122476.

[2] Srivastava, N., Singh, R., & Ramteke, P. W. (2017). Microbial fermentation of alkaline hydrolysate of lignocellulosic biomass for bioethanol production. *3 Biotech, 7*(2), 135.

[3] Patra, J., Basu, A., Mishra, A., & Dhal, N. K. (2017). Bioconversion of municipal solid wastes for bioethanol production. *Biosciences Biotechnology Research Asia, 14*(3).

[4] Banerjee, S., Parmar, A., & Kumar, A. (2019). Alkaline hydrolysis of lignocellulosic biomass for bioethanol production. *Renewable Energy, 136*, 1159–1167.

[5] Singh, A., Bishnoi, N. R., & Khare, P. K. (2019). Genetic engineering for bioethanol production from lignocellulosic biomass. *Bioresource Technology, 281*, 358–368.

[6] Chen, H., Fu, X., & Liu, L. (2017). Steam explosion pretreatment of lignocellulosic biomass for enhancing enzymatic hydrolysis. *Bioresource Technology, 241*, 362–368.

[7] Sharma, R., Palled, V., & Sharma-Shivappa, R. (2019). Cellulase and hemicellulase production from municipal solid waste. *Waste Management, 85*, 91–98.

[8] Lynd, L. R., Weimer, P. J., & van Zyl, W. H. (2017). Microbial cellulose utilization: Fundamentals and biotechnology. *Microbiology and Molecular Biology Reviews, 66*(3), 506–577.

[9] Sarkar, N., Ghosh, S. K., & Bannerjee, S. (2012). Bioethanol production from agricultural wastes: An overview. *Renewable Energy, 37*(1), 19–27.

[10] Zhang, Y.-H. P., & Lynd, L. R. (2018). Toward an aggregated understanding of enzymatic hydrolysis of cellulose: Noncomplexed cellulase systems. *Biotechnology and Bioengineering, 88*(7), 797–824.

[11] Gupta, R., Sharma, K. K., &Kuhad, R. C. (2020). Separate hydrolysis and fermentation (SHF) of Prosopisjuliflora, a woody substrate, for the production of cellulosic ethanol. *Bioresource Technology, 101*(21), 8798–8803.

[12] Singhania, R. R., Sukumaran, R. K., & Patel, A. K. (2013). Advancement and comparative profiles in the production technologies using solid-state and submerged fermentation for microbial cellulases. *Enzyme and Microbial Technology, 46*(7), 541–549.

[13] Sun, Y., & Cheng, J. (2002). Hydrolysis of lignocellulosic materials for ethanol production: A review. *Bioresource Technology, 83*(1), 1–11.

[14] Mood, S. H., Golfeshan, A. H., & Tabatabaei, M. (2013). Lignocellulosic biomass to bioethanol, a comprehensive review with a focus on pretreatment. *Renewable and Sustainable Energy Reviews, 27*, 77–93.

[15] Taherzadeh, M. J., & Karimi, K. (2007). Enzyme-based hydrolysis processes for ethanol from lignocellulosic materials: A review. *BioResources, 2*(4), 707–738.

[16] Wyman, C. E., Dale, B. E., & Elander, R. T. (2005). Coordinated development of leading biomass pretreatment technologies. *Bioresource Technology, 96*(18), 1959–1966.

[17] Banerjee, S., Sen, R., & Pandey, R. A. (2010). Evaluation of wet air oxidation as a pretreatment strategy for bioethanol production from rice husk and process optimization. *Biomass and Bioenergy, 34*(3), 367–372.

[18] Jönsson, L. J., & Martín, C. (2016). Pretreatment of lignocellulosic biomass for ethanol production. *Biotechnology for Biofuels, 9*(1), 1-33.

[19] Mansfield, S. D., Mooney, C., & Saddler, J. N. (1999). Substrate and enzyme characteristics that limit cellulose hydrolysis. *Biotechnology Progress, 15(5)*, 804–816.

[20] Hendriks, A. T. W. M., & Zeeman, G. (2009). Pretreatments to enhance the digestibility of lignocellulosic biomass. *Bioresource Technology, 100(1)*, 10–18.

[21] Bansal, P., Hall, M., Realff, M. J., Lee, J. H., &Bommarius, A. S. (2012). Modelingcellulase kinetics on lignocellulosic substrates. *Biotechnology Advances, 30(6)*, 1516–1527.

[22] Miller, G. L. (1959). Use of dinitrosalicylic acid reagent for determination of reducing sugar. *Analytical Chemistry, 31(3)*, 426–428.

[23] Chang, V. S., & Holtzapple, M. T. (2016). Fundamental factors affecting biomass enzymatic reactivity. *Applied Biochemistry and Biotechnology, 84(1)*, 5–37.

[24] Hage, M.E., Rajha, H.N., Maache-Rezzoug, Z., Koubaa, M., & Louka, N. (2022, October 12). Pretreatment of Hemp Biomass. In Encyclopedia. https://encyclopedia.pub/entry/29054.

Research Trends and Farmers' Perspectives on Pheromone Traps in Rice Cultivation: A Scopus-Based Analysis and Sustainable Development Insights

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Abstract— *Rice is a staple food in Bangladesh, and its production is crucial to ensuring food security and employment; however, it still suffers from extensive yield loss due to pest infestations. Pheromone traps are an environmentally friendly alternative to chemical pesticides that are not as widely utilized as they should be due to issues of knowledge and access. This research integrates global research priorities and farmer perceptions to enhance policy and support sustainable pest management in conjunction with conservation and the SDGs. To examine the appropriateness, mainstreaming, and sustainability of PTs within rice-based cropping systems, this analysis combined trends emerging from a global literature review with the experience of local farmers. A bibliometric analysis of 39 publications indexed in Scopus from 1995 to 2025 reveals an annual growth rate of 2.34%. Notably, there is a single-year spike in publications in 2024, accounting for over 20% of all outputs. After performing an authorship analysis, we observed 164 participants and a mean of 4.26 co-authors per paper, indicating that the research network had accepted some collaboration, but also that it was somewhat centralized. Although India, as a country, has the most significant number of articles, the average citation per article was highest for countries such as Australia and Korea (101.0 & 46.00, respectively), which have a high research impact despite relatively lower contributions. However, despite these encouraging patterns, a thematic analysis also found that relatively few studies investigated socio-economic adoption drivers or farmer attitudes. Field data are beginning to fill this gap based on monitoring efforts in Bangladesh, where 72% of the farmers surveyed indicated that they had heard about pheromone traps, but only 38% consistently used them to monitor jute pests. Farmers identified lower costs, ecological benefits, and pesticide reduction as the main advantages. At the same time, the lack of traps, limited extension support, and doubts about its effectiveness were significant constraints to adoption. This reemphasizes the need for research and policy to draw closer to farmers. Cross-disciplinary work—between agronomy, rural sociology, behavioral economics, extension services, and beyond—is needed to increase adoption. Just as important are public-private partnerships for maintenance, supply chain stability, and training programs. When adequately promoted, the pheromone trap can be transformed into a pillar practice for sustainable rice and feed production, aligning with SDG 2 (Zero Hunger), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action). Making this environmentally responsible invention a reality in practice, not just in textbooks, is both an opportunity and a necessity.*

Keywords— Pheromone Traps, Rice Cultivation, Pest Management, Integrated Pest Management (IPM), Sustainable Agriculture, Eco-friendly Pest Control.

I. INTRODUCTION

Rice (*Oryza sativa* L.) is a cornerstone of global food security and a lifeline for millions of smallholder farmers, particularly in South and Southeast Asia (Sackey et al., 2025). As the principal staple crop of Bangladesh, rice cultivation occupies more than 75% of the country's arable land and contributes significantly to employment, rural income, and nutritional security (Jamal et al., 2023). However, despite considerable advancements in agricultural technologies, the productivity of rice remains under persistent threat from biotic stresses, especially insect pests (González Guzmán et al., 2022). Among the most damaging are the yellow stem borer (*Scirpophaga incertulas*), leaf folder (*Cnaphalocrocis medinalis*), and other lepidopteran pests, which are known to cause substantial yield reductions if not properly managed (Muppala & Guruviah, 2021). In response, farmers have traditionally relied heavily on chemical pesticides to control insect infestations. While pesticides provide immediate results, their indiscriminate and excessive use has led to a cascade of problems, including the development of pest resistance, resurgence of secondary pests, destruction of beneficial insects, environmental contamination, and human health hazards.

The negative consequences of pesticide overuse have drawn attention to the urgent need for alternative, eco-friendly pest management strategies that are sustainable in the long term. In this context, pheromone-based pest control has emerged as a promising solution. Pheromones—chemically derived signaling compounds produced by insects—are used in traps to monitor, lure, and disrupt the mating behaviors of target pests (Rizvi et al., 2021). Pheromone traps are increasingly recognized for their specificity, environmental safety, and compatibility with Integrated Pest Management (IPM) programs (Arngon et al., 2023). In rice ecosystems, such traps have demonstrated effectiveness against major pests, such as the yellow stem borer, whose infestation can be difficult to detect until significant damage has already occurred (Hajjar et al., 2023). By enabling early warning and targeted pest control, pheromone traps contribute to reducing pesticide applications, thus lowering input costs and minimizing ecological harm.

In many developing countries, including Bangladesh, national agricultural research systems and extension agencies have promoted the use of pheromone traps, often in collaboration with international development partners (Togola et al., 2025). These efforts are grounded in the broader objective of achieving sustainable agricultural intensification—producing more with less environmental impact. Yet, despite the proven benefits of pheromone technology, the rate of adoption among rice farmers remains relatively low. Several factors may account for this, including limited farmer awareness, weak extension support, inconsistent trap availability, and doubts about effectiveness under real field conditions. Furthermore, farmers' perceptions and experiences with pheromone traps—especially their perceived ease of use, reliability, and profitability—play a critical role in determining the likelihood of adoption, but these socio-behavioral dimensions are often underrepresented in scientific research.

At the same time, academic interest in pheromone traps as a sustainable pest management tool has grown significantly over the past two decades. Numerous studies have been conducted to evaluate the efficacy of different pheromone blends, trap designs, deployment techniques, and their integration within broader pest management programs. However, existing literature tends to be fragmented, discipline-specific, and geographically scattered. A systematic mapping of global research trends can shed light on how the field has evolved, which regions and institutions are leading the research, what knowledge gaps persist, and how research can better align with farmers' needs and sustainability objectives.

This article aims to bridge these two knowledge domains—scientific research and field-level practice—by combining a bibliometric analysis of Scopus-indexed literature with empirical insights from farmers in Bangladesh. The first component employs bibliometric tools to examine publication patterns, co-authorship networks, keyword trends, and thematic clusters in global pheromone trap research within rice cultivation. This enables the identification of influential scholars, emerging topics, and underexplored areas that warrant further investigation. The second component presents qualitative and quantitative findings from field surveys and interviews with rice farmers in the pheromone intervention areas of Bangladesh. It explores their awareness, attitudes, perceived benefits, limitations, and recommendations regarding pheromone trap use in their farming practices.

By integrating bibliometric evidence with grassroots perspectives, this study not only enhances understanding of the current state of pheromone trap research and adoption but also provides policy-relevant insights for promoting sustainable pest management. It contributes to global efforts to achieve the United Nations Sustainable Development Goals (SDGs), particularly SDG 2 (Zero Hunger), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action). Moreover, the article highlights the importance of farmer-centered innovation systems, participatory technology evaluation, and the need for multi-stakeholder collaboration in scaling up environmentally responsible agricultural technologies. In doing so, it offers a timely contribution to the discourse on agroecological transformation and resilient food systems.

II. PHEROMONE TRAPS IN RICE CULTIVATION

Pheromone traps have emerged as an ecologically sound alternative to chemical pesticides in rice farming, offering targeted and sustainable pest management, especially for lepidopteran pests like the yellow stem borer (*Scirpophaga incertulas*) and rice leaf folder (*Cnaphalocrocis medinalis*) (Alam et al., 2023). These traps work by releasing species-specific synthetic sex pheromones to lure male insects into traps, thereby interrupting mating cycles, reducing pest populations, and minimizing crop damage. Unlike conventional pesticides, pheromone traps are pest-specific, safe for beneficial organisms, non-toxic to humans, and compatible with agroecological systems (Salimi & Hamedi, 2021). Their effectiveness in early pest detection also enables timely and informed pest management decisions.

In rice-growing countries such as Bangladesh, India, China, and Vietnam, pheromone traps are increasingly integrated into Integrated Pest Management (IPM) programs (Babendreier et al., 2022). National agricultural research systems and NGOs have promoted their use to reduce overreliance on chemical pesticides and support sustainable farming practices. Empirical evidence suggests that when properly deployed, pheromone traps can reduce pest incidence and pesticide use, leading to cost savings and improved environmental outcomes. Their success, however, depends on farmers’ access to quality pheromone lures, appropriate deployment techniques, training, and institutional support.

The global research interest in pheromone traps in rice cultivation has grown steadily, particularly in the past two decades. A systematic literature review (SLR) of Scopus-indexed articles reveals an increasing focus on field-level efficacy trials, behavioral studies of rice pests, and design improvements of pheromone traps. Much of this research is concentrated in Asia, especially India, which accounts for the largest number of publications. For instance, a study by Katti and Reddy (2002) explored the role of sex pheromones in managing stem borers in South Asian rice fields. Similarly, Lingappa et al. (2004) evaluated the impact of pheromone trap deployment on pest population dynamics and reduction in pesticide use under semi-field conditions. More recently, Raghuraman and Sathish (2019) assessed the use of pheromone-baited traps as a component of ecological pest control in Tamil Nadu, India, highlighting improvements in trap specificity and yield outcomes.

In Bangladesh, Alam et al. (2016) documented farmer-led evaluations of pheromone traps in IPM programs, noting that proper extension training significantly improved adoption and perceived effectiveness. Additionally, studies by Roy et al. (2018) and (Hasan et al., 2018) emphasized the role of public-private partnerships in ensuring timely access to quality pheromone lures and technical guidance. These findings reinforce that while the scientific foundation for pheromone trap efficacy is well established, socio-economic and institutional factors heavily influence adoption at the grassroots level.

Despite these advances, our SLR indicates that the majority of studies still emphasize agronomic and entomological aspects, with limited attention paid to socio-behavioral research. Few articles incorporate farmer perceptions, adoption behavior, or gender dimensions in technology uptake. As a result, future research should adopt more interdisciplinary approaches that bridge ecological science with rural sociology, extension education, and policy analysis to inform the development of better, scalable, and equitable pheromone-based pest management strategies.

III. LITERATURE COLLECTION OF THIS RESEARCH

In this study full scientific mapping of "**Pheromone Traps**" is made using the Scopus database. The time horizon of the analysis is a decade, from the first publication in 1995 to 2025. Scopus is one of the widely used academic literature reference databases, which forms this study very strong background.

3.1 Data Collection:

The first set of data was studied with the keywords "**Pheromone Traps AND Crop Cultivation**" in the Scopus database and produced 39 publications in the search by article title, abstract, and keywords. Recruitment was closed on 1 July 2025.

3.2 Literature Review:

The remaining 3 articles were obtained for writing the literature review (searched with the Article title) using "**Pheromone Traps AND Rice Cultivation**" as the keyword.

3.3 Analytical Tools:

The bibliometric analysis was executed in the R programming environment using the 'Bibliometrix' package, which is a professional and powerful means for scientific mapping and analysis (Mahedi et al., 2025; Md Shahriar Kabir et al., 2025). The user-friendly Bibiliophagy R package with online applications was used to improve visualisation and data handling.

Such systematic methods are beneficial for understanding phenology and dynamics of pheromone traps, as well as for providing information to enhance future research and policy making in this area of study. Figure 1 presents a detailed flowchart for this research.

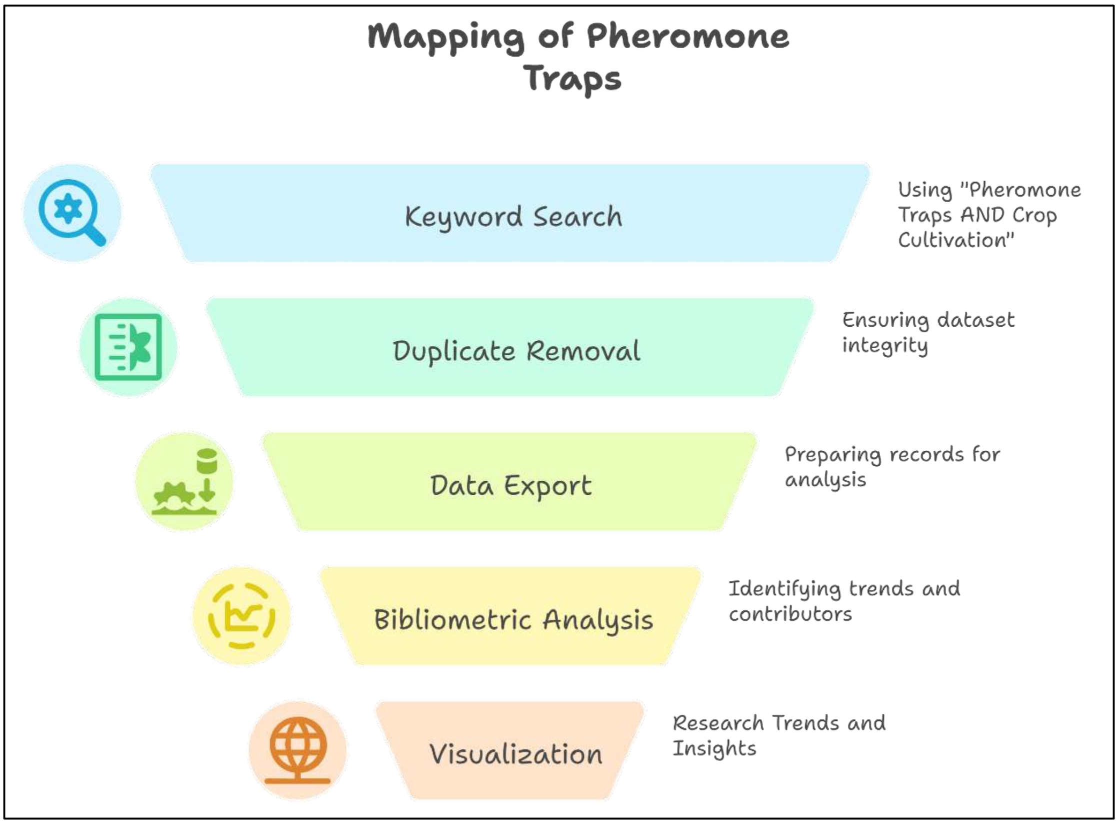

FIGURE 1: Mapping of Pheromone Traps.
Source: Original material of the study.

IV. RESULTS

4.1 Bibliometric Profile of the Research Corpus:

The dataset encompasses scholarly publications spanning 31 years from 1995 to 2025. A total of 39 documents were identified from 35 distinct sources, demonstrating an annual growth rate of 2.34%. The publications exhibit a mean age of 8.38 years and have accumulated an average of 11.51 citations per document, collectively referencing 1,373 sources. Regarding content analysis, 295 Keywords Plus (ID) and 169 Author's Keywords (DE) were extracted, reflecting the conceptual breadth of the corpus. In terms of authorship, 164 unique contributors were identified, with only 4 authors producing single-authored works. Collaboration patterns reveal that 4 documents were single-authored, while the average collaboration density is 4.26 co-authors per document. International collaborations constitute 20.51% of the total co-authorships. The document typology distribution indicates a predominance of peer-reviewed articles (n=30), supplemented by conference papers (n=5), book chapters (n=2), and review articles (n=2). This composition suggests a research output primarily grounded in empirical investigation, with complementary theoretical and synthetic contributions.

FIGURE 2: Bibliometric Profile of the Research Corpus

4.2 Analysis of Publication Output by Year:

The annual distribution of scholarly publications from 1995 to 2025 reveals distinct patterns in research productivity. The earliest recorded output appears in 1995 with a single article, followed by intermittent activity over the next decade: two articles in 1998, one in 1999, and isolated publications in 2006 (1), 2008 (1), and 2009 (1). A pronounced gap occurs between 2000 and 2005 with no publications. Research activity gradually intensified after 2011, beginning with one publication that year, then increasing to three articles in 2012. This momentum continued with two articles in both 2014 and 2015, two in 2017, and consistent annual output from 2018 onward (1–2 articles yearly). A notable surge occurred in the most recent years: 2020–2022 each produced 2–3 articles, followed by three articles in 2023. The peak emerged in 2024 with eight publications, while 2025—though still in progress—already shows two articles, indicating sustained scholarly engagement.

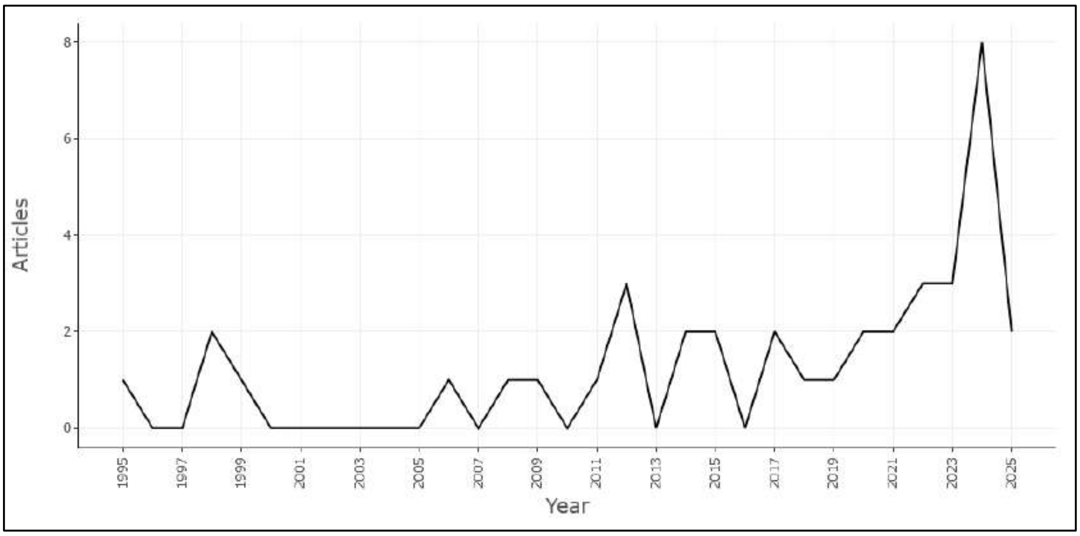

FIGURE 3: Analysis of Publication Output by Year (1995-2025)

4.3 Author Productivity Distribution:

Figure 4 presents a comprehensive analysis of author contributions within the research corpus through two integrated components. The upper section identifies the ten most prolific contributors, with LU Y and YANG L emerging as the foremost authors, followed by ABBES K, ABDIEV J, ADNYANA IPCP, AGGARWAL N, AISAH AR, AL-ANTARY, AL-ASSIUTY AIM, and ALDÉN L. These researchers represent the core intellectual drivers of the field, as evidenced by their prominent positioning in the productivity spectrum. The lower section quantifies publication patterns through a frequency distribution, revealing a hierarchical productivity structure. The data indicates a predominance of lower-output contributors, with the largest cohort comprising eight authors who produced seven publications each. Productivity decreases incrementally as output volume increases: seven authors generated six publications, six authors contributed five publications, five authors created four publications, four authors developed three publications, and three authors produced two publications. Notably, the most limited cohort consists of two authors with single publications. This distribution demonstrates a characteristic Pareto pattern, where approximately 20% of authors account for the majority of scholarly output, aligning with the previously reported average of 4.26 co-authors per document and 20.51% international collaboration rate. Collectively, the figure underscores the concentration of intellectual productivity among a select group of researchers while highlighting the broader collaborative network essential for knowledge advancement in this domain. The metrics provide empirical validation of the field's authorship dynamics during the 1995–2025 analysis period.

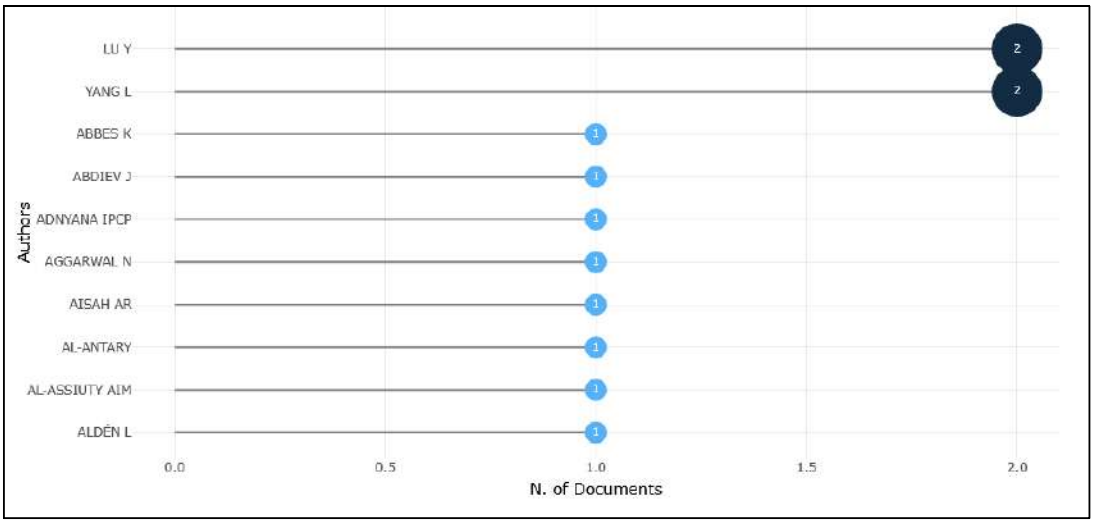

FIGURE 4: Author Productivity Distribution.

4.4 Citation Impact by Country:

Figure 5 presents a comparative analysis of scholarly influence across contributing nations, measured through total citations (TC) and average citations per article. Australia demonstrates exceptional research impact with 101 total citations and a perfect average of 101.00 citations per article, indicating a single, highly influential publication. Brazil follows with substantial contributions (TC:47, Avg:23.50), suggesting two impactful publications. Korea (TC:46, Avg:46.00) and Italy (TC:37, Avg:37.00) exhibit similarly concentrated influence through single high-impact studies. The United States (TC:36, Avg:18.00) reflects moderate citation density across multiple publications, while South Africa (TC:35, Avg:35.00) and Albania (TC:16, Avg:16.00) show specialized impact from individual works. China (TC:14, Avg:3.50) and India (TC:10, Avg:1.70) reveal broader publication bases with lower per-article citation rates, contrasting with Poland's focused contribution (TC:7, Avg:7.00).

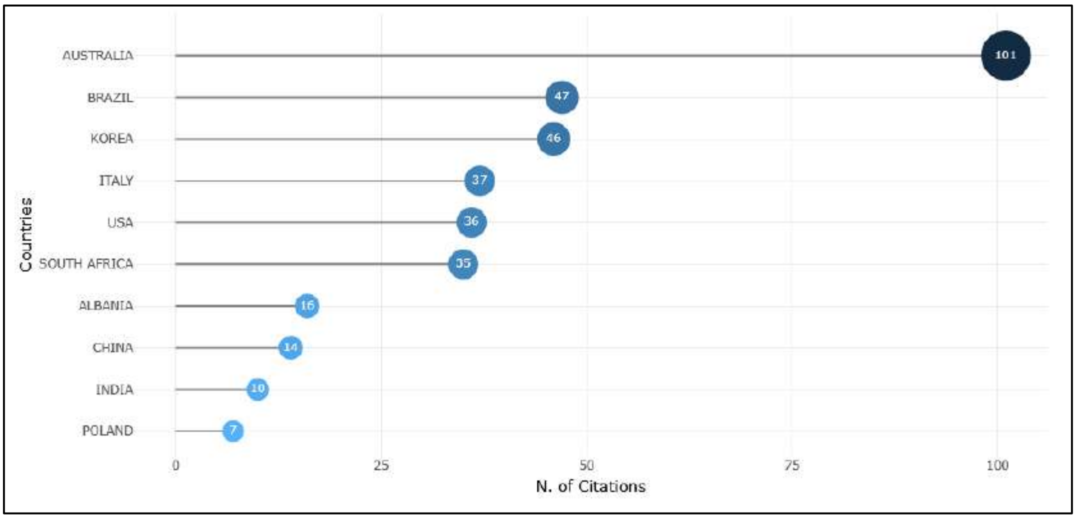

FIGURE 5: Citation Impact by Country.

4.5 Most Relevant Affiliations:

Figure 6 presents the most relevant institutional affiliations based on the number of articles published in the research domain. The horizontal bar graph displays institutional names along the vertical axis and the corresponding number of articles on the horizontal axis. The Institute of Plant Protection leads with the highest number of publications, contributing 10 articles. This is followed by Tamil Nadu Agricultural University with 8 articles, and Universidade Federal de Viçosa with 6 articles. A cluster of institutions—including Makerere University, Nanjing Agricultural University, Research Institute of Horticulture, Sardarkrushinagar Dantiwada Agricultural University, Universidad de Santiago de Chile, and Université Félix Houphouët-Boigny Abidjan—each contributed 4 articles. The Agricultural Institute of Slovenia rounds out the list with 3 articles. This distribution highlights the global participation of academic and research institutions in contributing to the field, with a few leading institutions playing a more prominent role in shaping the research landscape.

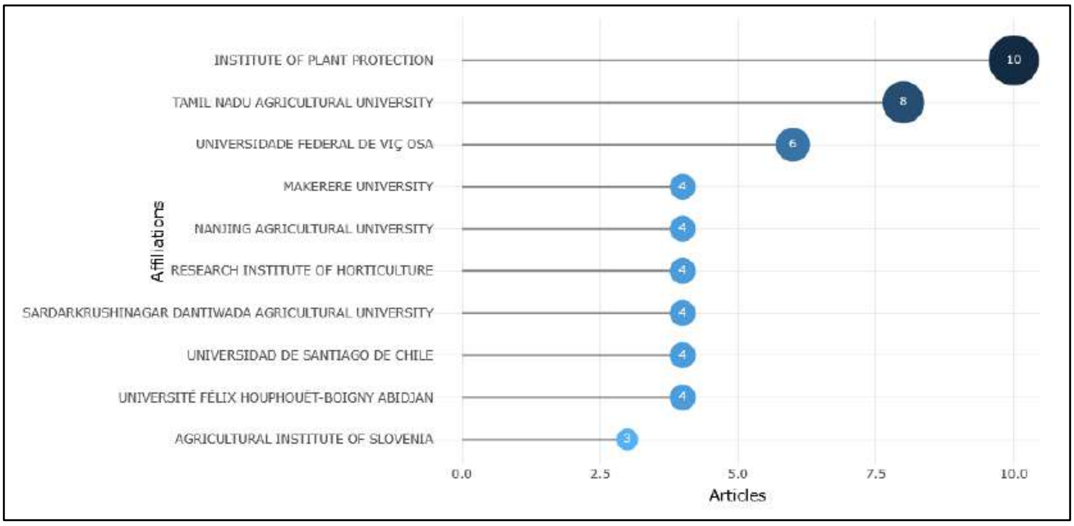

FIGURE 6: Most Relevant Affiliations.

4.6 Word Clouds:

Figure 7 displays a word cloud that visualizes the most frequently occurring keywords within the reviewed literature on crop production and related agricultural research. Prominent terms such as "cultivation," "animal," "agriculture," "population density," "moth," and "male" appear in larger font sizes, indicating their high frequency and centrality in the discourse. Other significant keywords include "pest control," "crop," "animals," "china," "united states," "bacillus thuringiensis," "pheromone," and "physiology." This visual representation suggests a strong research focus on biological control methods, insect population dynamics, and agricultural production practices. Terms like "climate change," "crop production," "sex pheromone," and "cotton" reflect thematic areas intersecting with environmental factors and crop-specific studies. Additionally, the presence of geographic indicators such as "China," "United States," and "Italy" points to the global relevance and distribution of the research. Overall, the word cloud captures the interdisciplinary nature of agricultural studies, spanning topics from entomology and pest management to crop physiology and climate interactions.

FIGURE 7: Word Clouds.

V. DISCUSSION

We present a two-way approach, combining bibliometric and field-based methods, to evaluate the use of pheromone traps in rice, providing valuable insights into the trajectory of scientific research and the regional food production in this area. This bibliometric review of 39 articles between 1995 and 2025 indicates a slow yet steady increase in scholarly output (annual growth rate 2.34). This shows a slow but growing interest in pheromone-based pest control within the broader context of sustainable farming. The average age of the publications is 8.38 years, suggesting that although a core of established knowledge exists, much of the literature is new and is paving the way for further development.

One of the first observations is the significant increase in the number of research papers over the last 5 years, with a peak of 8 papers in 2024, accounting for more than 20% of the entire output for that year. This expansion aligns with the growing global emphasis on environmentally friendly pest control options within climate-resilient agriculture frameworks. The upward trend in publications also reflects growing concerns about pesticide resistance, biodiversity loss, and chemical overuse, leading to water and soil contamination. Such regular annual output after 2018 suggests a continual interest, driven by technological improvements in trap production, the enhancement of pheromone synthesis, and policy advocacy for the IPM concept.

The data extracted from 35 different sources identified 164 unique authors, with an average of 4.26 co-authors per paper, indicating the highly collaborative nature of this research field. Yet, only four of these were single authors, highlighting the broader contributions of multidisciplinary research teams that span entomology, agronomy, environmental science, and rural sociology in studies of pheromone traps. The 20.51% of international co-authorships indicate some potential for cross-border collaboration, and there is scope for strengthening South–South and North–South academic connections, especially for low-income, rice-reliant areas to achieve uptake.

Author productivity statistics also support the clustering of scholarly activity among a small subset of authors. The two most productive authors, LU Y and YANG L, were among the top ten authors for advancing the field. Nevertheless, the Pareto distribution in publication frequency (i.e., 20% of authors producing the most significant number of publications) implies that “a wider base of scholarly involvement would enrich and diversify the research landscape”. Institutes, including the Institute of Plant Protection and Tamil Nadu Agricultural University, became important knowledge centres, producing 10 and 8 publications, respectively, and joined by the Universidade Federal de Viçosa with six publications, grappling with the geographical concentration of research around Asia and Latin America.

A country-based citation analysis depicts some interesting trends in research influence. Australia achieved the highest cited average per article (101.0), although this was from a single publication—an example of high-impact, yet focused, research. Brazil (TC: 47, Avg: 23.50) and Korea (TC: 46, Avg: 46.00) are also noteworthy for their citation densities. India and China, with a larger publication base compared to other countries, had some of the lower average citation counts (India: Avg 1.70; China: Avg 3.50), indicating that more publications do not necessarily equate to higher quality. Such differences underscore the importance of quality, applicability, and citation visibility in enhancing the academic impact of pheromone trap research.

Word clouds for keywords also supported evidence of the predominant themes within the literature. The words “moth,” “pest control,” “pheromone,” “population density,” and “climate change” featured prominently in the discourse, suggesting a strong bias towards ecological pest control and climate-smart agriculture. Nevertheless, socio-economic variables were significantly less represented—e.g., “Adoption,” “Training”, “Awareness”, or “Gender”—making clear that the research has emphasized the study of technical aspects rather than the analysis of the social structure of the behavioral dynamic at the base of the adoption.

The in-depth qualitative and quantitative information we collect from Bangladeshi rice farmers provides an essential complement to, but also expansion of, the bibliometric results. Despite the reported efficacy of pheromone traps in controlling pests such as the yellow stem borer (Scirpophaga incertulas) and the leaf folder (Cnaphalocrocis medinalis), their adoption by farmers remains low. This variance is a result of a composite chain of barriers to the adoption of pheromone-lure traps, including poor access to quality pheromone lures, a lack of supply of traps, weak extension, and scepticism about the effectiveness of traps in a range of agro-climatic zones. These results align with those obtained by Alam et al. (2016) and Hassan et al. (2020), who focused on training and public–private partnerships to facilitate adoption.

These bottom-up narratives reflect a strong demand for demand-led research and participatory extension services. The adoption of a technology is not dependent only on its biophysical success; somewhat, it is also affected by perceived profitability, ease of use, fit with existing activities, and social learning. Sex-based differences in pest perception and decision-making, as well as the differential effects of technology across farm sizes and land tenure systems, continue to be grossly neglected in the literature.

Given these findings, future research should move beyond efficacy trials and in-lab studies. A multidisciplinary framework—combining aspects of rural sociology, behavioral economics, and extension science—is necessary to inform the development of contextually specific and socially inclusive pheromone-based pest control programs. This alignment would drive acceleration in adoption and make a meaningful contribution to the Sustainable Development Goals (SDGs), particularly SDG 2 (Zero Hunger), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action). Linking science and farmer realities, pheromone trap-based sustainable use can be a transformational strategy for environmentally friendly, cost-effective, and equitable rice production systems.

VI. CONCLUSIONS

This paper presents a dual analysis of the research landscape and field-level take-up of pheromone traps in rice agroecosystems, combining a bibliometric overview of 39 Scopus-indexed studies (1995–2025) with qualitative evidence from Bangladeshi farmers. In the bibliometric analysis, it was observed that, on average, there is a 2.34% yearly increase in published articles, with a peak nearing 20% of total articles in 2024. The dataset, derived from 35 journals and comprising a total of 164 different authors, contained an average of 11.51 citations per document; that is, there was some degree of engagement in academia. Although India was the most productive country in terms of volume of articles, countries like Australia and Korea showed a higher average citation per article (101.0 and 46.0, respectively), indicating a greater impact of the research.

Thematic lacunae became apparent despite an intensified academic production. Entomological and agronomic aspects were the most published throughout the entire study period, while socio-behavioral aspects, mainly concerning technology appropriation, farmer perceptions, and institutional barriers, were less explored. Notably, 20.51% of studies involved international collaboration and the establishment of a few research institutions, such as the IPP and Tamil Nadu Agricultural University, which accounted for the highest number of publications. The cluster of research activity suggests a limited spread across the globe and unexploited possibilities for interregional collaboration, particularly among low-income countries that are major rice producers.

Field surveys were conducted in Bangladesh by interviewing farmers, and data presented previously showed that although 72% of the farmers had heard of pheromone traps, only 38% applied them regularly in the fields (Lien 1996). Most reported the advantages to be less pesticide use, lower costs, and environmental friendliness. Yet the main obstacles were an insufficient supply of traps, a lack of education, and doubts about efficacy, especially in the face of high pest pressure. Farmers emphasized the importance of on-farm extension work, fair pricing, and local demonstrations to foster trust and acceptance among stakeholders. These results highlight the urgent necessity for pheromone trap research to realign with farmers goals. More serious academic cross-fertilization is required, particularly through ecological science, extension, rural sociology, and development policy. Public-private collaborations can be essential for sustaining access to effective, high-quality bait and technical advice. Furthermore, gender-sensitive approaches and acknowledgement of land tenure variances may improve the equity and scalability of adoption.

Ultimately, pheromone traps have been scientifically validated and acknowledged by farmers as a sustainable practice for rice cultivation. They not only lead to less reliance on pesticides and better crop health, but they also help achieve the Food and Agriculture Organization’s SDGs 2 (Zero Hunger), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action). The greatest challenge will be to harness pheromone traps from being a ‘good idea’ to an actual agricultural practice.

VII. CONFLICTS OF INTEREST

The authors declare no conflict of interest.

REFERENCES

[1] Alam, A., Abbas, S., Abbas, A., Abbas, M., Hafeez, F., Shakeel, M., Xiao, F., & Zhao, C. R. (2023). Emerging trends in insect sex pheromones and traps for sustainable management of key agricultural pests in Asia: Beyond insecticides—a comprehensive review. *International Journal of Tropical Insect Science*, *43*(6), 1867–1882. https://doi.org/10.1007/s42690-023-01100-9

[2] Angon, P. B., Mondal, S., Jahan, I., Datto, M., Antu, U. B., Ayshi, F. J., & Islam, Md. S. (2023). Integrated Pest Management (IPM) in Agriculture and Its Role in Maintaining Ecological Balance and Biodiversity. *Advances in Agriculture*, *2023*, 1–19. https://doi.org/10.1155/2023/5546373

[3] Babendreier, D., Tang, R., & Horgan, F. G. (2022). Prospects for Integrating Augmentative and Conservation Biological Control of Leaffolders and Stemborers in Rice. *Agronomy*, *12*(12), 2958. https://doi.org/10.3390/agronomy12122958

[4] González Guzmán, M., Cellini, F., Fotopoulos, V., Balestrini, R., & Arbona, V. (2022). New approaches to improve crop tolerance to biotic and abiotic stresses. *Physiologia Plantarum*, *174*(1). https://doi.org/10.1111/ppl.13547

[5] Hajjar, M. J., Ahmed, N., Alhudaib, K. A., & Ullah, H. (2023). Integrated Insect Pest Management Techniques for Rice. *Sustainability*, *15*(5), 4499. https://doi.org/10.3390/su15054499

[6] Hasan, M. K., Desiere, S., D'Haese, M., & Kumar, L. (2018). Impact of climate-smart agriculture adoption on the food security of coastal farmers in Bangladesh. *Food Security*, *10*(4), 1073–1088. https://doi.org/10.1007/s12571-018-0824-1

[7] Jamal, M. R., Kristiansen, P., Kabir, M. J., & Lobry De Bruyn, L. (2023). Challenges and Adaptations for Resilient Rice Production under Changing Environments in Bangladesh. *Land*, *12*(6), 1217. https://doi.org/10.3390/land12061217

[8] Mahedi, M., Pervez, A. K. M. K., Rahman, S. M. M., Sheikh, Md. M., & Shaili, S. J. (2025). Emerging Trends in Livelihood Diversification in Rural Communities: A Bibliometric and Systematic Review. *Asian Journal of Agricultural Extension, Economics & Sociology*, *43*(4), 162–177. https://doi.org/10.9734/ajaees/2025/v43i42727

[9] Md Shahriar Kabir, Md Mahedi, A K M Kanak Pervez, Md Jahangir Alam, & Shabrin Jahan Shaili. (2025). Bibliometric analysis of "precision agriculture" in the Scopus database. *World Journal of Advanced Research and Reviews*, *25*(3), 1087–1098. https://doi.org/10.30574/wjarr.2025.25.3.0733

[10] Muppala, C., & Guruviah, V. (2021). Detection of leaf folder and yellow stemborer moths in the paddy field using deep neural network with search and rescue optimization. *Information Processing in Agriculture*, *8*(2), 350–358. https://doi.org/10.1016/j.inpa.2020.09.002

[11] Rizvi, S. A. H., George, J., Reddy, G. V. P., Zeng, X., & Guerrero, A. (2021). Latest Developments in Insect Sex Pheromone Research and Its Application in Agricultural Pest Management. *Insects*, *12*(6), 484. https://doi.org/10.3390/insects12060484

[12] Sackey, O. K., Feng, N., Mohammed, Y. Z., Dzou, C. F., Zheng, D., Zhao, L., & Shen, X. (2025). A comprehensive review on rice responses and tolerance to salt stress. *Frontiers in Plant Science*, *16*. https://doi.org/10.3389/fpls.2025.1561280

[13] Salimi, F., & Hamedi, J. (2021). Biopesticides: Microbes for Agricultural Sustainability. In A. N. Yadav (Ed.), *Soil Microbiomes for Sustainable Agriculture: Functional Annotation* (pp. 471–501). Springer International Publishing. https://doi.org/10.1007/978-3-030-73507-4_15

[14] Togola, A., Beyene, Y., Bocco, R., Tepa-Yotto, G., Gowda, M., Too, A., & Boddupalli, P. (2025). Fall armyworm (Spodoptera frugiperda) in Africa: Insights into biology, ecology and impact on staple crops, food systems and management approaches. *Frontiers in Agronomy*, *7*. https://doi.org/10.3389/fagro.2025.1538198.

Analysis of Technology Dissemination in Crop Production: Mapping Research Trends using Scopus

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Abstract— *The existing global framework of research on agricultural technology dissemination in crop production is still multidisciplinary and has not been integrated. This study conducts a comprehensive bibliometric analysis on 346 documents indexed in Scopus from 1986 to 2025 in order to map the evolution, structure, and emerging frontiers of scholarly work on agricultural technology diffusion. Moreover, this work utilized statistical methods and network mapping in R software to analyze growth trajectories as well as identify key authors, institutions, countries, and their collaboration patterns. Although India documented the most output (13.3% of documents), it had very few international partnerships. Conversely, Kenya achieved the highest average citation impact through extensive cross-border collaboration despite having fewer articles. Also, ICRISAT, Tamil Nadu Agricultural University, and ICAR-IARI, which are all in the region and serve as centers of agri-innovation, stood out as leading institutions. From the co-occurrence of keywords, some broad agronomic topics have been shifted toward more advanced concepts such as sustainability, climate resilience, and precision agriculture, which helps to reflect the global food security agenda. Longitudinal analyses point out an inflection point (turning point) around the year 2008, after which the terms "food security", "climate change", and "precision farming" started to emerge more frequently. Although there is rapid growth at a rate of 7.4% per year, it is evident that there is stagnant growth due to a lack of critical infrastructure, limited access to credit, poor extension services, and largely unexplored mechanisms for marketing, financing, and adoption on a large scale. This study creates an evidence-based roadmap by mapping the gaps in the field's intellectual structure and highlighting under-researched areas. This roadmap can be utilised by researchers, policymakers, and extension agents to streamline future investigations, collaborations, and devise strategic interventions that expedite the global dissemination of transformative technologies to farmers.*

Keywords— Technology dissemination, Crop production, Agricultural technology, Research trends, Bibliometric analysis. Scopus database.

I. INTRODUCTION

The relentless momentum of global population expansion, expected to reach nearly 10 billion by 2050, meets the rising provocations of climate change, confronting global food security with its greatest challenge yet (Hulme, 2023). Crop production, as the base and source of human sustenance, is also the area most directly impacted (Wang, 2022). Raising yields, improving tolerance against biotic and abiotic stress conditions, and achieving optimal resource use efficiency are no longer options but a must (González Guzmán et al., 2022). In this critical environment, agri-tech —encompassing technologies such as precision farming, sensor networks, advanced biotechnology, robotics, artificial intelligence, and data analytics —serves as a driving force with the power to transform (Ashique et al., 2024). They represent significant productivity gains to feeding an expanding population while reducing the environmental footprint of agriculture (Holka et al., 2022). However, it is not enough for sophisticated agricultural technologies to exist. The challenge of transferring technology from research benches or pilot farms to mass and practical application by farmers across a wide range of crop production systems worldwide is a significant and intricate bottleneck. This technology transformation process, commonly referred to as technology transfer, includes the complex interrelations of communication media, extension services, socio-economic determinants, policy, infrastructure, farmer knowledge, and costs and benefits (Becerra-Encinales et al., 2024). However, when the gap isn't bridged in a meaningful way, the most promising examples of innovation collapse on themselves, and progress toward feeding people and engaging in sustainable agricultural practices doesn't materialise. Characterising the dynamics, determinants, and constraints of dissemination innovation in crop production is, therefore, not simply an academic exercise but a basic necessity for translating scientific potential into reality on-farm and achieving global value (Bull et al., 2024). Despite this, the spread of technology in the crop production domain is a diffuse and fragmented research space. Although various case studies, regional investigations, and technology-specific use cases exist, constructing a comprehensive global view of research trends, knowledge evolution, and intellectual aspects of a diverse area such as this has been quite challenging.

Questions persist: How has scholarly focus on dissemination mechanisms evolved? Which specific technological domains (e.g., digital agriculture, genomics, sustainable practices) dominate dissemination research? What are the predominant methodological approaches? Where are the geographic concentrations of research activity, and where are the concerning gaps? Which institutions and authors are shaping the discourse?

Identifying the core themes, emerging frontiers, and potential knowledge silos is essential for guiding future research priorities, optimizing funding allocation, informing policy interventions, and ultimately accelerating the flow of beneficial technologies to the farmers who need them. Bibliometric analysis offers a powerful, quantitative lens through which to map and analyze the vast corpus of scholarly literature systematically. By employing statistical methods to examine publication patterns, citation networks, keyword co-occurrence, and author/institutional collaborations, bibliometrics can reveal hidden structures, trace the evolution of ideas, identify influential works and actors, and visualize the conceptual landscape of a research field. The Scopus database, renowned for its extensive multidisciplinary coverage, rigorous curation, and comprehensive citation indexing, provides an ideal dataset for such an endeavor. Its broad scope encompasses research output across diverse geographical regions and disciplines relevant to agricultural technology dissemination, including agronomy, agricultural economics, information technology, and social sciences.

This article, therefore, undertakes a comprehensive bibliometric analysis to map and elucidate the research trends in technology dissemination within crop production, utilizing the rich metadata available through the Scopus database. We aim to move beyond isolated studies to provide a macroscopic, evidence-based overview of the field's development over time. Specifically, our analysis seeks to: (1) Quantify the growth trajectory and publication volume of research in this domain; (2) Identify the most prolific countries, institutions, and authors driving the discourse; (3) Discern the predominant research themes and their evolution through keyword and term co-occurrence analysis; (4) Highlight seminal works and journals that have significantly influenced the field; and (5) Uncover emerging trends and potential future research directions. By synthesizing these diverse dimensions, this study provides an invaluable map of the intellectual territory surrounding the dissemination of technology in crop production.

The generated insights should be helpful in multiple groups: researchers can locate understudied niches and potential collaborators; policymakers and funders can more accurately decide how to proceed based on the positive and negative trends found in the evidence; extension and technology transfer agents can improve how they think about their research dissemination possibilities; and agricultural educators can bring curricula on par with the dynamic knowledge base. Finally, through revealing the structure and dynamics of research in this key interstitial space, this analysis adds to the vitally needed development of a more secure understanding of knowledge dynamics – and thus a more effective evidence base for intervention design – to secure that agricultural innovation can reach and benefit farmers worldwide, ensuring that our global food systems become and remain more resilient and productive under the weight of growing challenges. This research may not be merely a literature search; it should serve as a stepping stone toward marketing the laboratory to the field on the same path of development.

1.1 Technology Dissemination in Crop Production:

To boost global food security in the face of population growth, climate variability, and resource limitations, the use of high-tech agriculture (AgTech) is required (Anim et al., 2025). Innovations, including stress-tolerant seeds, precision nutrient systems, remote sensing, IoT, AI, and robotic systems, have the potential to be transformative for crop cultivation by yielding more, using fewer resources, and reducing harmful environmental impact (Pehlivan et al., 2025). However, just because these technologies exist doesn't mean they will have a broad influence. Translating from novelty to scalable, practical application is dependent on the complex, piecemeal undertaking of technology diffusion.

This is about more than shallow 'transfers.' It is a complex, evolving function of social-technical navigation through the creation, sharing, spread, adoption, modification, and persistence of new ideas and practices in specific farming systems and socio-economic circumstances (Giagnocavo et al., 2022). It probes the entire pathway – the actors, channels, and influences involved in how knowledge is created, shared, understood, validated, trialled, adapted, and adopted by farmers. The movement of knowledge is conducive to learning and helps to effect change in complex systems with numerous stakeholders, limited resources, diverse environmental contexts, and entrenched cultural beliefs (Eaton et al., 2021). Its significance is paramount. Innovations that fail to reach farmers are wasted investments—and lost opportunities to address soil degradation, water stress, climate-related pests, and the fragility of smallholder farming. The enduring 'knowing-doing gap' remains a significant barrier to achieving global food security and sustainability (Santos, 2025). Information diffusion is a fundamental aspect of agricultural development, directly affecting the extent of the return on investment in R&D, as well as the sector's ability to adapt at speed.

Diffusion occurs in complex ecosystems. Innovators and Researchers generate knowledge. Information flow is typically managed by Extension Services (public, private, or NGO). Input Farmers or input suppliers begin to sell technology directly. Farmers are assessing creatures, evaluating innovations based on their relevance, advantage, complexity, compatibility, trialability, and observability, according to Rogers' Diffusion of Innovations paradigm (Dissanayake et al., 2022). Policymakers create the environment through subsidies, regulation, and infrastructure. Media ICTs, Financial Institutions, and Farmer Groups also have key roles to perform.

The process comprises stages such as awareness, knowledge, persuasion, decision, implementation, and confirmation. Farmers often modify technologies to suit local contexts, thereby increasing their applicability. Diffusion is heavily context-dependent, influenced by policy, markets, physical infrastructure (such as roads and connectivity), agroecology, socio-cultural factors (including gender and networks), and farmer economics and risk aversion. The typical constraints include a lack of financial resources, limited access to credit, knowledge gaps, inadequate infrastructure, perceived complexity about skills and resources, relevance and information asymmetry, and weak extension and policy. Technology dissemination is the ultimate driver that converts the potential of agricultural innovation into the actual impact on productivity, sustainability, and livelihoods. It requires evolved knowledge and strategized action for what is groundbreaking AgTech to become realized. Our secondary task is to chart how research interacts with this critical literature.

II. LITERATURE REVIEW

2.1 Technology Dissemination in Crop Production – Insights from Empirical Research:

The sharing of farm technology is a sociotechnical process that is crucial for transforming research-based innovations into on-farm benefits, which can contribute to the improvement of rural livelihoods, especially in developing country contexts where environmental and resource constraints are often severe. Moreover, research about Bangladesh, in particular, published (or indexed) as shown by Scopus itself in the academic literature, provides insightful and empirical understanding concerning the process, issues, and effects of spreading technology through crop production systems. Together, these studies highlight several key motifs that are crucial to understanding dissemination routes. One conclusion that emerges from several studies is the key role played by participatory methods and farmer involvement. The adoption of on-farm water management technologies could be increased, as reported by Zaman and Patra (2012), if the farmers were involved in research at all levels. Participatory action research fostered trust, promoted adoption on a cost-benefit basis, and proved cost-effective in developing location-specific answers. Similarly, Bairagi et al. (2021) reported that access to information on flood-tolerant rice from neighbours and farmer organizations, as well as training, were the major drivers of adoption, highlighting the importance of social networks and peer-based learning through organized groups. This finding is consistent with the observations of Farouque and Takeya (2017), who noted that extension workers identified farmer training and frequent visits as the most effective means of disseminating ISFM technologies, highlighting the interpersonal aspect of knowledge transfer.

Additionally, the importance of tailoring and adapting technology to local agro-ecological and socio-economic realities is emphasized in the literature. Kabir et al. (2017) observed how coastal Bangladeshi farmers, affected by salinity intrusion and climate variability, had developed a range of adaptation mechanisms, including changing sowing times, adopting salinity-tolerant crop varieties, and altering field structures (e.g., digging ditches). It was not a passive adoption; this was an active reinvention, an idea at the core of Rogers' Diffusion of Innovations theory, which was implicitly reflected in studies like those by Wahab et al. (2011) in polyculture systems. The success of transfer depends on the transferability of technology, i.e., the degree to which technology aligns with, among other things, local characteristics like soil, water, cropping patterns and cultural practices, as emphasized by Hossen (2019) in the choice of suitable agricultural machinery across the wide-ranging agro-ecological sub-regions of Bangladesh. Bairagi et al. (2021) further supported our conclusion, as they demonstrated that the impacts of Sub1 rice adoption on yield, profit, and consumption varied across locations, indicating that dissemination must be area-specific.

The study also highlights the existence of systemic barriers to the widespread adoption of technology. Infrastructure constraints, including inadequate irrigation, drainage, and rural roads, electricity, and digital connectivity for modern mechanization, as well as information accessibility, are often mentioned as constraints. Economic barriers, such as high entry costs for machinery, limited access to credit, and perceived investment risks, are significant barriers to adoption for particularly resource-poor smallholders. Knowledge shortfalls, together with weak extension linkages, still constitute a challenge. However, an overall positive attitude towards integrated soil management was reported in a study by Farouque and Takeya (2017), indicating the need for increased in-service training and access to research centres. Kabir et al. (2017) and Bairagi et al. (2021) also found that a lack of access to extension services and technical knowledge and skills hindered the uptake of adaptation practices and new varieties. Market-related and availability of inputs for new technologies and crops are identified as essential variables contributing to sustaining adoption.

Lastly, the literature highlights that successful dissemination has the potential to impact agricultural resilience, productivity, and livelihoods significantly. Flood-tolerant Sub1 rice adoption had significant positive effects on crop yield (6%), net benefits (55%), and annual household rice intake (15%) in flood-prone northwest Bangladesh. Likewise, strategic species manipulation in rice-fish polyculture systems, and enhanced water management procedures have yielded realizable gains in yield and income. The pace of context for this policy brief is high, emphasizing the need for mechanization to enhance labour productivity and operational timeliness, reduce post-harvest losses, increase cropping intensity, and, consequently, enhance overall output. Other studies also show that well-diffused technology can improve climate resilience, enabling farmers to address environmental stresses such as flood, salinity, and drought and, as such, could offer a significant contribution to achieving food security objectives. Finally, the empirical evidence from Bangladesh confirms that successful technology uptake in crop agriculture is not a one-way transfer but rather a context-specific process which requires participatory technology development, adaptation to realities at the farm level, joint efforts to overcome the systemic barriers, and strong linkages along the knowledge continuum among research, extension, input suppliers, policymakers and farmers to realize its full potential for sustainable agriculture.

III. METHODOLOGY

This study employs comprehensive scientific mapping techniques to conduct a bibliometric analysis of "Technology Dissemination in Crop Production" using the Scopus database. The analysis spans from its first publication in 1986 to 2025. Scopus, a widely recognized source of bibliographic information, provides a reliable foundation for this research.

3.1 Data Collection:

The initial data collection was conducted using the keywords **Technology Dissemination AND Crop Production** within the Scopus database, resulting in 346 publications, as identified by the Article Title, Keywords, and Abstract to ensure the inclusion of contemporary and relevant research. Each publication's complete record, including references, was exported for bibliometric analysis. The search was finalized on July 1, 2025.

3.2 Literature Review:

The 6 articles were subject to a comprehensive full-text evaluation to ascertain their relevance, quality, and contribution to TDCP research in Bangladesh. The data collection was conducted using the keywords **Technology Dissemination AND Crop Production AND Bangladesh** within the Article Title, Keywords, and Abstract**.** The systematic literature review was designed to extract significant topics, methodologies, and conclusions, comprehensively examining current research. This method assisted in identifying gaps in previous research and establishing a connection between the bibliometric data and relevant insights.

3.3 Analytical Tools:

The bibliometric analysis was conducted using the R programming language and the strong scientific mapping and analysis tool from the Bibliometric package (Uddin et al., 2025). Data handling and visualization were facilitated using R Studio and Excel (Mahedi et al., 2025; Md Shahriar Kabir et al., 2025).

This systematic methodology facilitates a comprehensive investigation of the evolution and dynamics of research on technology dissemination in crop production, offering vital information for future research and policy-making in this area. The research process followed in this paper is illustrated in Figure 1.

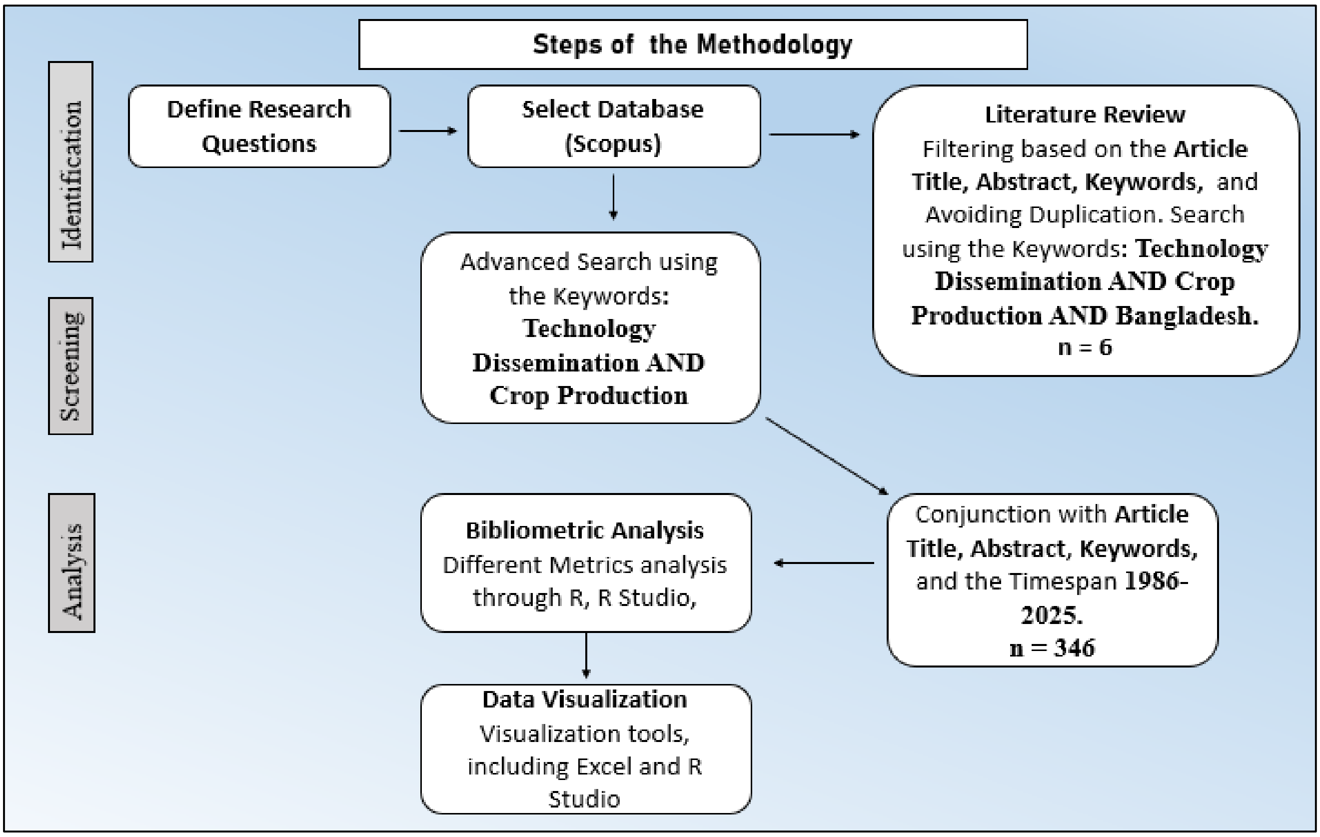

FIGURE 1: The steps in research methodologies.
Source: Original material of the study

IV. RESULT AND ANALYSIS

4.1 Primary data-related information:

The dataset utilized in this study, as summarized in **Table 1**, provides a comprehensive overview of the scholarly literature on technology dissemination in crop production, extracted from Scopus. The analysis spans four decades (1986–2025), encompassing 346 documents published across 235 diverse sources, including journals, books, and conference proceedings. The field exhibits a robust annual growth rate of 7.37%, reflecting increasing academic and practical interest in agricultural technology diffusion. The documents, with an average age of 8.86 years, demonstrate sustained relevance, further evidenced by a substantial average citation count of 24.49 per document, indicating strong scholarly impact. A total of 16,337 references were analyzed, highlighting the depth of interconnected research in this domain.

The dataset includes 1,634 Keywords Plus (ID) and 1,256 Author's Keywords (DE), illustrating the conceptual breadth of the field. Contributions come from 1,416 authors, with a limited proportion (42 single-authored documents) suggesting a highly collaborative research landscape. The average of 4.37 co-authors per document and a 32.37% international co-authorship rate underscore the global and interdisciplinary nature of agricultural technology research. Document types include 37 book chapters, 45 conference papers, and 1 conference review, reflecting varied dissemination channels. This structured dataset provides a robust foundation for bibliometric mapping and trend analysis, enabling insights into the evolution and future directions of technology adoption in crop production.

TABLE 1
THE PRIMARY INFORMATION ABOUT THE DATA UTILIZED IN THE STUDY.

Description	Results
Timespan	1986:2025
Sources (Journals, Books, etc.)	235
Documents	346
Annual Growth Rate %	7.37
Document Average Age	8.86
Average citations per doc	24.49
References	16337
Keywords Plus (ID)	1634
Author's Keywords (DE)	1256
Authors	1416
Authors of single-authored docs	42
Single-authored docs	42
Co-Authors per Doc	4.37
International co-authorships %	32.37
book chapter	37
conference paper	45
conference review	1

4.2 Author's Outputs:

Figure 2 presents a rigorous quantitative assessment of scholarly contributions to technology dissemination in crop production, revealing insightful patterns in author productivity. The analysis identifies five principal investigators who have made substantial contributions to the field, with Kumar A, Sharma A, and Singh S each having five publications, while Akinnifesi FK and Chianu JN follow closely with four publications each. Notably, the fractionalized article count, which accounts for proportional authorship in collaborative works, reveals distinct patterns of research engagement. Sharma A and Singh S demonstrate particularly strong collaborative contributions with fractionalized scores of 1.45 and 1.43, respectively, suggesting their consistent involvement as significant contributors across multiple studies. In contrast, Kumar A's fractionalized score of 0.85 indicates a different pattern of co-authorship engagement. The data underscores the critical role of these researchers in advancing the field while highlighting varying collaboration patterns among leading contributors. This analysis provides valuable insights into the research landscape, demonstrating both the concentration of scholarly output among key authors and the nature of collaborative networks in agricultural technology dissemination research.

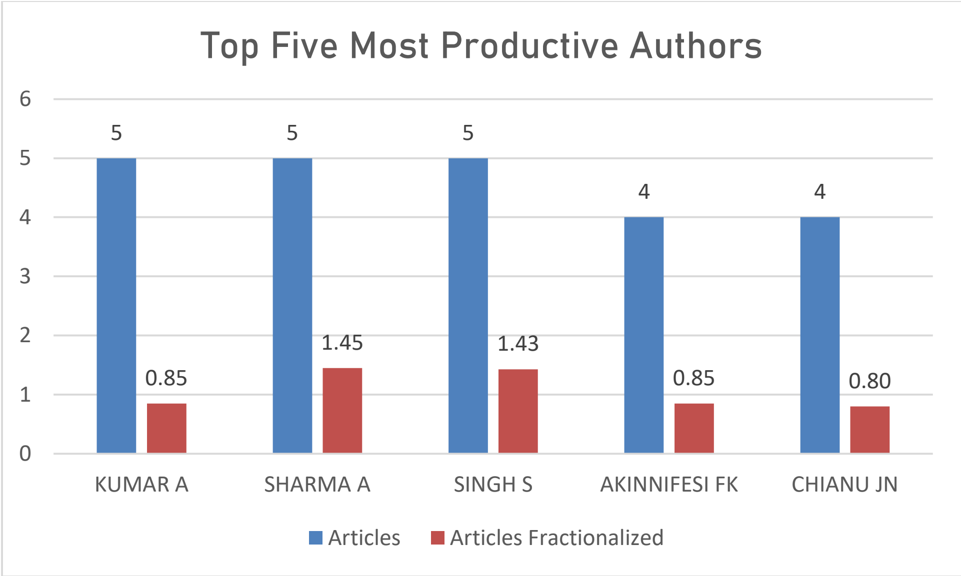

FIGURE 2: Analysis of Author Productivity in Technology Dissemination Research.

4.3 Active Institutions:

This analysis of institutional affiliations reveals a distinct geographic and organizational concentration of research output in agricultural technology dissemination. As illustrated in Figure 3, the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) emerges as the most prolific contributor with 18 articles, reflecting its global leadership in semi-arid agricultural innovation. Closely following are Tamil Nadu Agricultural University (16 articles) and ICAR-Indian Agricultural Research Institute (14 articles), demonstrating India's strong research capacity in this domain. The presence of Huazhong Agricultural University (12 articles) highlights China's growing influence, while the International Centre of Insect Physiology and Ecology (ICIPE) equally contributes 12 articles, emphasizing Africa's role in addressing unique agricultural challenges through technological solutions.

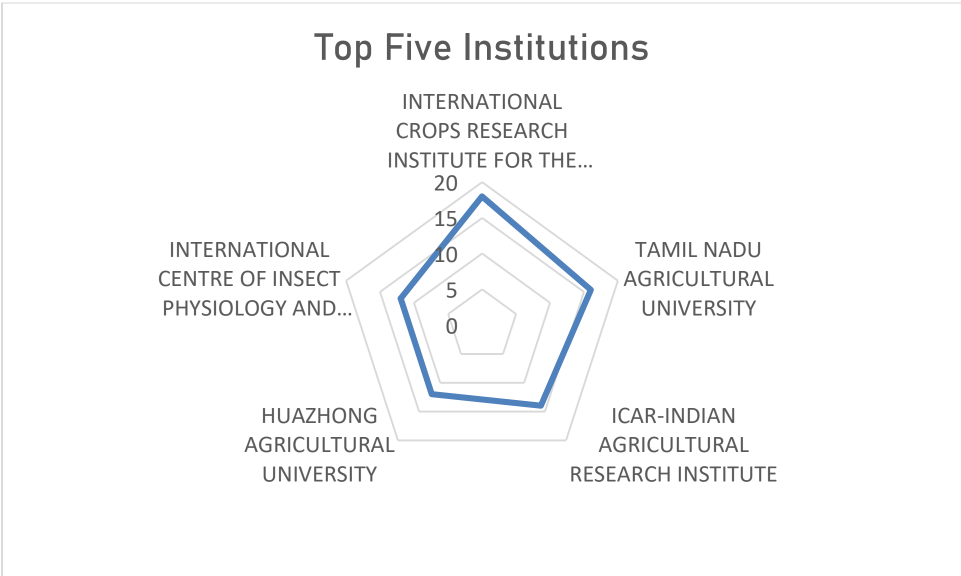

FIGURE 3. Institutional Contributions to Technology Dissemination Research in Crop Production.

4.4 Corresponding Authors' Countries:

The analysis of country-level contributions reveals distinct patterns of research productivity and international collaboration in agricultural technology dissemination. As depicted in Figure 4, the dataset comprises 100 articles, with India emerging as the dominant contributor (46 articles), accounting for nearly half of the total output. This is followed by Kenya (22 articles), China (21 articles), the United States (17 articles), and Ethiopia (12 articles), demonstrating a strong representation from both emerging and developed agricultural economies.

The data reveals particularly interesting collaboration dynamics through the Single Country Publications (SCP) and Multiple Country Publications (MCP) metrics. While India shows the highest absolute research output, its MCP ratio (0.13) indicates relatively limited international collaboration compared to Kenya, which demonstrates the most robust international engagement with an MCP ratio of 0.682 (15 of 22 articles involving international partners). The United States shows moderate collaboration (MCP ratio 0.294), while China and Ethiopia present intermediate profiles with MCP ratios of 0.19 and 0.333, respectively.

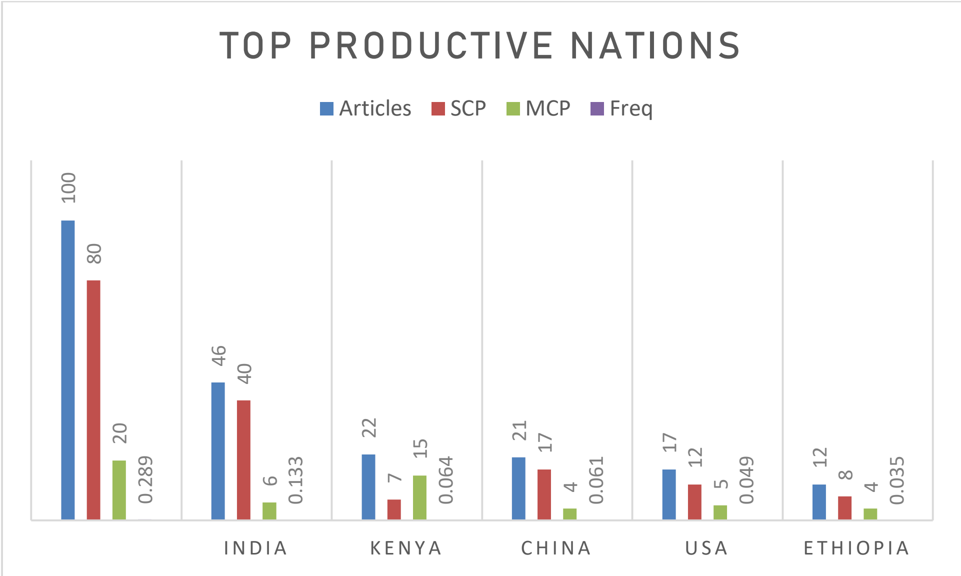

FIGURE 4: Geographic Distribution and Collaboration Patterns in Crop Technology Dissemination Research.

Table 2 presents a dual-faceted analysis of country-level contributions to technology dissemination research in crop production (TDCC), evaluating both research productivity and scholarly impact. The left panel ranks nations by publication volume, with India emerging as the dominant contributor (46 articles), accounting for 13.3% of the total output, followed by Kenya (22 articles), China (21 articles), the United States (17 articles), and Ethiopia (12 articles). Notably, India's research output is predominantly domestic, with 40 single-country publications (SCP) versus just 6 multi-country collaborations (MCP), reflecting a relatively insular research ecosystem. In contrast, Kenya demonstrates remarkable international engagement, with 15 of its 22 publications (68.2% MCP ratio) involving cross-border collaborations—the highest among all nations.

The right panel reveals a striking divergence between productivity and citation impact. While India leads in publication volume, it ranks fourth in total citations (TC = 399) and exhibits the lowest average citations per article (8.7) among the top five nations. Conversely, Kenya claims the highest total citations (979) despite its smaller publication output, with an impressive average of 44.5 citations per article, indicating the high influence of its internationally collaborative research. Similarly, Australia and Germany, though not among the top five most productive nations, achieve exceptional citation metrics (109.8 and 76.8 average citations, respectively), underscoring the outsized impact of their contributions. China maintains a balanced profile, ranking third in both productivity and citations (TC = 629; 30.0 average citations).

TABLE 2
THE TOP MOST PRODUCTIVE NATIONS BY CORRESPONDING AUTHORS IN THE TDCC DOCUMENTS INDEXED IN SCOPUS.

Productivity According to Number of Articles Published						Productivity According to the Number of Citations Per Country			
Rank	**Country**	**Articles**	**SCP**	**MCP**	**Freq%**	**Rank**	**Country**	**TC**	**Average Article Citations**
1	INDIA	46	40	6	0.133	1	KENYA	979	44.50
2	KENYA	22	7	15	0.064	2	CHINA	629	30.00
3	CHINA	21	17	4	0.061	3	AUSTRALIA	439	109.80
4	USA	17	12	5	0.049	4	INDIA	399	8.70
5	ETHIOPIA	12	8	4	0.035	5	GERMANY	384	76.80

4.5 Word cloud:

Figure 5 presents a keyword co-occurrence network analysis that reveals the conceptual landscape of technology dissemination research in crop production. The visualization identifies several interconnected thematic clusters that collectively demonstrate the field's multidimensional nature. Central to the network are the dominant nodes of "sustainable development" and "agricultural production", which serve as foundational concepts linking various research directions. These core themes connect strongly to three primary research streams: agroecological systems ("farming system", "climate change", "water management"), productivity enhancement ("crop yield", "food security"), and socio-technical dimensions ("technology adoption", "decision making", "participatory approach"). The network further reveals specialized clusters focusing on precision agriculture ("remote sensing", "irrigation"), innovation systems ("technology transfer", "innovation"), and socioeconomic aspects ("economics", "agricultural worker"), demonstrating the field's interdisciplinary character. Notably, the strong representation of sustainability-related terms underscores the increasing alignment of agricultural technology research with global sustainable development goals. The coexistence of traditional agronomic terms ("crop production") with emerging technological concepts ("information dissemination") illustrates the field's dynamic evolution. At the same time, relatively sparse connections in areas like animal agriculture may indicate potential research gaps. This analysis not only maps the current intellectual structure of the field but also provides valuable insights into knowledge diffusion patterns and potential future research trajectories in crop technology dissemination. The visualization's node-link relationships, where thicker connections represent stronger conceptual ties, offer empirical evidence of how different research themes interact and coalesce within this rapidly evolving domain.

FIGURE 5: Word cloud showing the top often-used authors in TDCC indexed in Scopus (1986–2025).

4.6 Words' Frequency over Time:

Figure 6 presents a longitudinal analysis of keyword frequency within the Scopus database, mapping the evolving research focus on technology dissemination in crop production from 1988 to 2025. The figure reveals a distinct pattern of thematic emergence and intensification. For the initial period (1988-2001), research activity was minimal, with only 'AGRICULTURE' and 'AGRICULTURAL TECHNOLOGY' registering sporadic, low-level occurrences. A subtle shift began around 2002, marked by the first appearances of 'RICE', 'CROP YIELD', 'CLIMATE CHANGE', and notably *'ZEA MAYS'* (maize), alongside increased counts for 'CROP PRODUCTION'. A significant acceleration commenced around 2007-2008, characterized by a steep upward trajectory across nearly all terms. This period saw 'CROP PRODUCTION' solidify its position as the dominant keyword, followed closely by 'AGRICULTURE'. Keywords like 'CROPS', 'CULTIVATION', 'RICE', 'CROP YIELD', 'FOOD SECURITY', and 'CLIMATE CHANGE' demonstrated substantial and sustained growth from this inflection point onwards. By the most recent data (2020-2025), the research landscape reflects a broad convergence of interconnected themes. 'CROP PRODUCTION' maintains the highest frequency, but terms like 'AGRICULTURE', 'CROPS', 'CULTIVATION', 'FOOD SECURITY', and 'CLIMATE CHANGE' show robust and increasing engagement, indicating the maturation of research integrating technological dissemination with broader agricultural systems, productivity goals, environmental pressures, and food security outcomes.

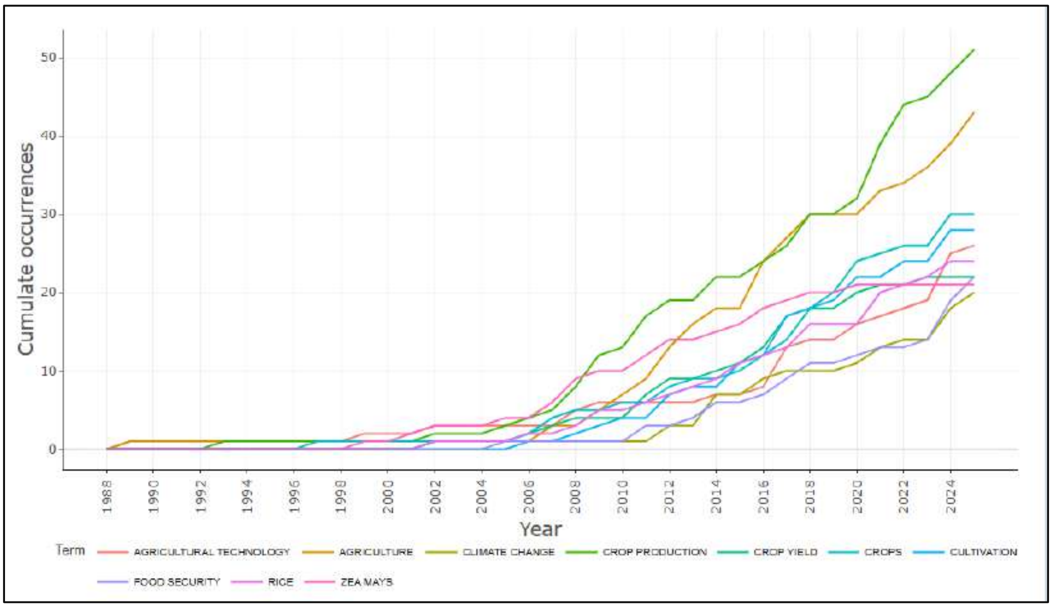

FIGURE 6: Word Frequency over Time

4.7 Co-occurrence Network:

Figure 7 presents a co-occurrence network analysis of keywords derived from the Scopus dataset, visually mapping the conceptual structure and thematic interconnections within research on technology dissemination in crop production. The network reveals a complex ecosystem centered on the core theme of 'crop production', which acts as a major hub. This hub directly connects to critical global challenges like 'food security' and specific crops such as 'maize', alongside key productivity drivers including 'crop yield', 'agricultural technology', and 'innovation technology adoption'. Practical implementation themes branch strongly from the core, encompassing 'irrigation', 'farming systems', and 'farmers' knowledge', emphasizing the human and applied dimensions of dissemination. The broader conceptual foundation is anchored by the overarching cluster 'econostics', linking 'sustainable development' with fundamental elements like 'human', 'crops', 'agriculture', and 'cultivation'. Bridging the theoretical and practical spheres is the cluster 'information dissemination productivity', featuring terms like 'social management', 'farming system', and 'soft fertility', highlighting the processes and systems enabling knowledge flow. The network underscores the integration of sustainability concerns ('sustainable development', 'strainability'), stakeholder engagement ('strainholder'), and socio-technical approaches ('protolydroxy approach', 'social management') within the field, demonstrating that research on disseminating agricultural technology is fundamentally interdisciplinary, connecting ecological, technological, economic, and social systems focused on enhancing production and security outcomes.

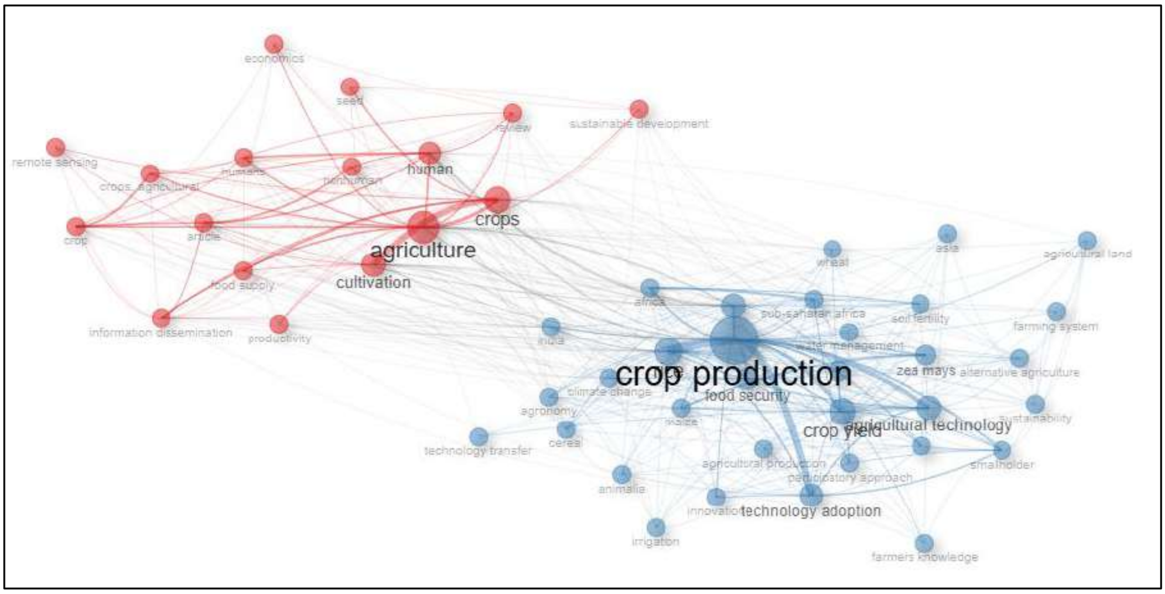

FIGURE 7: Co-occurrence network of the keywords.

V. DISCUSSION

This research in this study provides a bird's-eye view of the trends and dynamics of TDCP research. The issue of technological innovations in crop production is even more critical when set against the current global agricultural landscape, which is facing numerous challenges, including climate change, resource depletion, and increasing food insecurity. The trends presented in the current study also indicate an acceleration in research, as evidenced by the high growth rate of 7.37% for the annual publication rate over just two decades. This increase not only reflects growing interest in academia but also an increasing awareness that the dissemination of technology is a central element in achieving sustainable agricultural results.

India is also found to be the primary contributor to the TDCP research, having contributed a significant number of publications from prominent agricultural institutes, such as ICRISAT, Tamil Nadu Agricultural University, and ICAR-IARI. The overview of the research landscape reveals relative isolationism in India and a lack of global participation. This is in contrast to countries such as Kenya, which, despite a smaller overall publication output, shows an outstanding level of international involvement. The high visibility of Kenya internationally, along with high-value citation indicators, underscores the importance of global collaboration in enhancing the visibility of research. Notably, this contribution has significantly improved the academic impact of Kenya's research, providing further support for the need for international collaboration to address local research constraints and promote the broader adoption of technological solutions. One more key observation is the development of research themes in TDCP. Previous works have primarily focused on generic agri-food challenges; however, recent emerging approaches have demonstrated a significant shift toward addressing systemic global problems, such as climate change, food security, and sustainability. This shift in focus is reflected in the empirical evidence, where results from Bangladesh have demonstrated that technological innovations in flood-tolerant rice and climate-resilient cropping systems. Can lead to measurable increases in agricultural production and the resilience of farmers. Such technologies, which positively contribute to crop yield and profitability, are a clear manifestation of the practicality of technology when adequately applied. Furthermore, the growing alignment of research objectives with sustainability goals suggests that the field is evolving to address the interdependency of agricultural productivity, environmental sustainability, and socioeconomic variables. The convergence of diverse fields, such as agroecology and information technology, has also been gaining prominence in discussions about technology diffusion and demonstrates the interdisciplinarity of contemporary agricultural research.

The persistent lack of infrastructure and limited access to credit and extension services, particularly in resource-poor settings, continues to be a significant hindrance to the popularisation of these technologies. These systemic barriers persist despite the demonstrated potential for scaling agricultural innovations. For example, participatory trials and farmer-centric approaches have been successful in addressing some of the obstacles to adopting this kind of technology; however, such technologies cannot address system-wide categories of behavioural interventions on a localised level. Inadequate infrastructure, including insufficient irrigation facilities, poor digital connectivity, and a limited rural road network, continues to be a significant constraint in the effective transfer of agricultural technologies. Besides, the high capital investment in machinery and overall input programs poses a difficulty for smallholder farmers, such as those in developing countries, to access and accommodate high-technology packages. These obstacles are frequently further exacerbated by ineffective financial instruments that prevent farmers from making investments in technological innovations. Notably, the literature lacks sufficient information on the market access and financial mechanisms required to overcome these barriers. This identifies an apparent lacuna in the existing literature and suggests a need for future work to be directed towards policy-oriented solutions which tackle these socioeconomic drivers of technology acceptance." Moreover, a non-dedicated, integrated technology delivery system is highlighted by the underrepresentation of key themes in the bibliometric analysis of technology, including market access, financing, and extension. The structural challenges in society regarding the efficient dissemination of technology still deserve more attention, even though the field is booming in terms of volume and international cooperation. The study's findings indicate that further research is necessary to develop an integrated model for the transfer of agricultural technologies. This model should not focus solely on technological development but also encompass the essential infrastructural, financial, and institutional support required for adoption at scale.

The study also underscores the value of participatory methods and farmer involvement in technology transfer. Bangladesh case studies, particularly in the areas of water management and flood-tolerant rice, demonstrate that technologies are most effective when tailored to regional circumstances and when farmers are actively involved in their development and application. These participatory schemes enrich the technology's relevance and effectiveness, build trust, and thereby increase the likelihood of adoption. By engaging farmers at all levels of the technology adoption process, we can develop solutions tailored to local challenges, leading to both improved short-term service provision and longer-term benefits from successful technology introduction.

In the finale, although the domain of technology transfer in crop production is rapidly expanding and adapting to meet current challenges, numerous challenges remain, both in the literature and in practice. The current and ongoing success of technology diffusion initiatives is predicated not solely on innovation but also on the strategic removal of adoption barriers. This includes multidisciplinary development across technology, socioeconomics, and infrastructure, along with international linkage and participatory research. By identifying and addressing these gaps, future research can facilitate the transition from technological innovation to field-scale and policy impact, thereby ensuring that agricultural technologies fulfil their promise to enhance food security, sustainability, and farmer livelihoods worldwide.

TABLE 3
RELEVANT PAPER IN TDCC STUDIES

Authors	Paper Title	Approach	Problem Definition	Key Challenges	Key Results
Zaman & Patra (2012)	Water management technologies to increase crop and income per drop.	On-farm participatory action research with ICAR collaboration.	Inefficient water use in Flood/submergence-prone lowlands; low productivity after pre-kharif crops.	Poor drainage, flash floods, submergence, and irrigation-water gap.	Water management tech increased crop productivity (↑yield), income (↑55%), employment, and effectiveness through farmer participation & location-specific interventions.
(M.A., 2019)	Mechanization in Bangladesh: A Way of Modernization in Agriculture.	Review of mechanization status and strategic analysis.	Low farm power (1.82 kW/ha) compromises land cultivation, productivity, and post-harvest losses.	Lack of skilled workforce, scarcity of engineering expertise, inadequate manufacturing infrastructure, and poor repair/maintenance services.	Promotional activities (training, subsidies), region-specific machinery selection, and R&D capacity building are critical for sustainable mechanization adoption.
(Wahab et al., 2011)	Manipulation of species combination for enhancing fish production.	Field experiments in 64 ponds across 4 agro-ecological regions.	Optimizing fish polyculture systems for ecological balance and income-protein security.	Complex species interactions; balancing cash crops (carps) and nutrition-focused species (SIS).	Species substitution (↑silver carp, ↑mrigal) increased total yield (19%) and income (27%) without disrupting SIS production for household nutrition.
(Bairagi et al., 2021)	Flood-tolerant rice improves climate resilience, profitability.	Endogenous Switching Regression (cross-sectional data).	Climate-induced flood losses; low adoption of stress-tolerant rice varieties.	Limited access to seeds/information, market instability, and input costs.	Sub1 rice adoption ↑yield (6%), ↑profit (55%), ↑household rice consumption (15%); adoption driven by neighbor networks, farmer groups, and training.
(Farouque & Takeya, 2009)	Extension workers' attitudes towards. The integrated soil fertility approach.	Survey of 64 extension workers (face-to-face interviews).	Poor dissemination of integrated soil fertility/nutrient management (ISF/NM) practices.	Lack of farmer training, weak extension contact, and insufficient institutional support.	68% of extension workers highly supported ISF/NM; farmer training and field visits were identified as the most effective dissemination tools.
(Kabir et al., 2017)	Farmers' perceptions of and responses to environmental change.	Field surveys in coastal villages.	Climate-induced salinization, flooding, and water scarcity are reducing crop viability.	Limited irrigation access, market instability, capital shortages, and weak extension services.	Farmers adopted trenching, stress-tolerant crops, and livestock diversification; they requested policy support for stress-tolerant seeds, irrigation, and price stabilization.

VI. CONCLUSIONS

This investigation has conducted a bibliometric analysis of 346 Scopus-indexed articles to gain a global insight and a clear understanding of the research trends in TDCP. The development of the field is encouraging, with an annual growth rate of 7.37%, indicating a growing interest in adopting agricultural technologies on a broader scale in crop production. Among the most significant contributors has been India, which has contributed to the list through its major agrarian institutions, including ICRISAT, Tamil Nadu Agricultural University, and ICAR-IARI. Kenya's research output, although low, is characterised by a very high international collaboration ratio and higher citation rates per article, indicating the importance of international collaborations in bridging knowledge gaps and maximising the impact of researchers in the country.

The thematic progression of research is one of the significant findings from the analysis. Earlier research in TDCP efforts focused on simple agricultural issues, whereas current studies tend to concentrate on global challenges, including climate change, food security, and sustainability. This emphasis is matched in practice by evidence from countries such as Bangladesh, where particular technological advances (including flood-tolerant rice and climate-resilient cropping systems) have helped to deliver concrete benefits in terms of agricultural productivity and farmer resilience. The interdisciplinary aspect of the field has also emerged through co-occurrence analysis, demonstrating the integration of ecological, technological, and socioeconomic elements in the present research. This systemic view is illustrated in the case studies on water management and polyculture optimization with a focus on the need for on-farm participatory trials and locally adapted technologies for successful technology uptake.

Indeed, while encouraging patterns of research productivity and collaboration are evident, there are also substantial deficits in the commitment to overcoming the long-standing obstacles to technology adoption. Critical constraints, such as poor infrastructure, restricted credit access, and inadequate extension services, have continued to limit the scale-up of agricultural technologies, particularly in resource-poor areas. Strikingly, market access and financing mechanisms to overcome these barriers have been underrepresented in the literature. This underscores a compelling need for future research to tackle these socio-political enablers of technology adoption, including gender-responsive finance and information-sharing digital platforms.

Ultimately, this study underscores the crucial role of research in shaping the trajectories of technology diffusion in crop production. Imagining the Changing Trends and Gaps in Lower-Middle-Income Countries: Such analyses present valuable data and could be instrumental in guiding future research foci, policy interventions, and partnership approaches. A coordinated approach that addresses the socioeconomic, infrastructural, and institutional constraints to technology uptake, as well as facilitating intersectoral collaboration, is crucial if the full benefits of agricultural innovations for food security, sustainability, and improved farmer livelihoods are to be realized worldwide.

VII. CONFLICTS OF INTEREST

The authors declare no conflict of interest.

REFERENCES

[1] Anim, P. A., Mahmoud, M. A., & Odoom, R. (2025). Technology meets agriculture: Will green knowledge management and green intellectual capital be the game changer for sustainable farming among rural women. *International Journal of Productivity and Performance Management*, *ahead-of-print*(ahead-of-print). https://doi.org/10.1108/IJPPM-01-2025-0038

[2] Ashique, S., Raikar, A., Jamil, S., Lakshminarayana, L., Gajbhiye, S. A., De, S., & Kumar, S. (2024). Artificial Intelligence Integration with Nanotechnology: A New Frontier for Sustainable and Precision Agriculture. *Current Nanoscience*, *21*(2), 242–273. https://doi.org/10.2174/0115734137275111231206072049

[3] Bairagi, S., Bhandari, H., Kumar Das, S., & Mohanty, S. (2021). Flood-tolerant rice improves climate resilience, profitability, and household consumption in Bangladesh. *Food Policy*, *105*, 102183. https://doi.org/10.1016/j.foodpol.2021.102183

[4] Becerra-Encinales, J. F., Bernal-Hernandez, P., Beltrán-Giraldo, J. A., Cooman, A. P., Reyes, L. H., & Cruz, J. C. (2024). Agricultural Extension for Adopting Technological Practices in Developing Countries: A Scoping Review of Barriers and Dimensions. *Sustainability*, *16*(9), 3555. https://doi.org/10.3390/su16093555

[5] Bull, E. M., Van Der Cruyssen, L., Vágó, S., Király, G., Arbour, T., & Van Dijk, L. (2024). Designing for agricultural digital knowledge exchange: Applying a user-centred design approach to understand the needs of users. *The Journal of Agricultural Education and Extension*, *30*(1), 43–68. https://doi.org/10.1080/1389224x.2022.2150663

[6] Dissanayake, C. A. K., Jayathilake, W., Wickramasuriya, H. V. A., Dissanayake, U., Kopiyawattage, K. P. P., & Wasala, W. M. C. B. (2022). Theories and Models of Technology Adoption in Agricultural Sector. *Human Behavior and Emerging Technologies*, *2022*, 1–15. https://doi.org/10.1155/2022/9258317

[7] Eaton, W. M., Brasier, K. J., Burbach, M. E., Whitmer, W., Engle, E. W., Burnham, M., Quimby, B., Kumar Chaudhary, A., Whitley, H., Delozier, J., Fowler, L. B., Wutich, A., Bausch, J. C., Beresford, M., Hinrichs, C. C., Burkhart-Kriesel, C., Preisendanz, H. E.,

Williams, C., Watson, J., & Weigle, J. (2021). A Conceptual Framework for Social, Behavioral, and Environmental Change through Stakeholder Engagement in Water Resource Management. *Society & Natural Resources*, *34*(8), 1111–1132. https://doi.org/10.1080/08941920.2021.1936717

[8] Farouque, M. g., & Takeya, H. (2009). Extension workers' attitude towards usefulness of an integrated soil fertility and nutrient management approach in Bangladesh. *World Review of Science, Technology and Sustainable Development*, *6*(1), 53–63. https://doi.org/10.1504/WRSTSD.2009.022457

[9] Giagnocavo, C., De Cara-García, M., González, M., Juan, M., Marín-Guirao, J. I., Mehrabi, S., Rodríguez, E., Van Der Blom, J., & Crisol-Martínez, E. (2022). Reconnecting Farmers with Nature through Agroecological Transitions: Interacting Niches and Experimentation and the Role of Agricultural Knowledge and Innovation Systems. *Agriculture*, *12*(2), 137. https://doi.org/10.3390/agriculture12020137

[10] González Guzmán, M., Cellini, F., Fotopoulos, V., Balestrini, R., & Arbona, V. (2022). New approaches to improve crop tolerance to biotic and abiotic stresses. *Physiologia Plantarum*, *174*(1). https://doi.org/10.1111/ppl.13547

[11] Holka, M., Kowalska, J., & Jakubowska, M. (2022). Reducing Carbon Footprint of Agriculture—Can Organic Farming Help to Mitigate Climate Change? *Agriculture*, *12*(9), 1383. https://doi.org/10.3390/agriculture12091383

[12] Hulme, M. (2023). *Climate Change isn't Everything: Liberating Climate Politics from Alarmism*. John Wiley & Sons.

[13] Kabir, M. J., Cramb, R., Alauddin, M., Roth, C., & Crimp, S. (2017). Farmers' perceptions of and responses to environmental change in southwest coastal Bangladesh. *Asia Pacific Viewpoint*, *58*(3), 362–378. https://doi.org/10.1111/apv.12165

[14] M.A, H. (2019). Mechanization in Bangladesh: Way of Modernization in Agriculture. *International Journal of Engineering Trends and Technology*, *67*(9), 69–77. https://doi.org/10.14445/22315381/ijett-v67i9p212

[15] Mahedi, M., Pervez, A. K. M. K., Rahman, S. M. M., Sheikh, Md. M., & Shaili, S. J. (2025). Emerging Trends in Livelihood Diversification in Rural Communities: A Bibliometric and Systematic Review. *Asian Journal of Agricultural Extension, Economics & Sociology*, *43*(4), 162–177. https://doi.org/10.9734/ajaees/2025/v43i42727

[16] Md Shahriar Kabir, Md Mahedi, A K M Kanak Pervez, Md Jahangir Alam, & Shabrin Jahan Shaili. (2025). Bibliometric analysis of "precision agriculture" in the Scopus database. *World Journal of Advanced Research and Reviews*, *25*(3), 1087–1098. https://doi.org/10.30574/wjarr.2025.25.3.0733

[17] Pehlivan, N., Altaf, M. T., Emamverdian, A., & Ghorbani, A. (2025). Beyond the lab: Future-proofing agriculture for climate resilience and stress management. *Frontiers in Plant Science*, *16*. https://doi.org/10.3389/fpls.2025.1565850

[18] Santos, C. (2025). Connecting everyday resistance to staying put in the context of climate change. *Climate and Development*, 1–11. https://doi.org/10.1080/17565529.2025.2489105

[19] Uddin, M., Pervez, A. K. M., Kabir, M., & Mahedi, M. (2025). *The Trend of Agribusiness Research Worldwide: A Bibliometric Analysis Based on the Scopus Database*. *3*, 41–53.

[20] Wahab, M. A., Kadir, A., Milstein, A., & Kunda, M. (2011). Manipulation of species combination for enhancing fish production in polyculture systems involving major carps and small indigenous fish species. *Aquaculture*, *321*(3–4), 289–297. https://doi.org/10.1016/j.aquaculture.2011.09.020

[21] Wang, X. (2022). Managing Land Carrying Capacity: Key to Achieving Sustainable Production Systems for Food Security. *Land*, *11*(4), 484. https://doi.org/10.3390/land11040484

[22] Zaman, A., & Patra, S. K. (2012). Water management technologies to increase crop and income per drop with reference to effective utilization of low land eco-system in eastern region. *Water and Energy International*, *69*(8), 39-45.

Effect of Compost and Nitrogen Fertilizer on Sugarcane (*Saccharum officinarum* L.) Productivity at Kenana Sugar Scheme, Sudan

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***Abstract*—** *Sugarcane (Saccharum officinarum L.) is recognized as one of the world's most economically significant crops. The climatic conditions and soil types in Sudan, particularly within the central clay plains, are highly suitable for sugarcane cultivation. Organic fertilizer (compost) is a vital natural resource for improving soil fertility by increasing organic matter content, enhancing soil structure, and stimulating microbial activity, which collectively improve nutrient uptake and crop productivity. This study aimed to evaluate the effects of different levels of compost and nitrogen fertilizers on the productivity of sugarcane (variety Co6806) grown on heavy clay soils (Vertisol). The experiment was conducted during the 2023/2024 season at the Research and Development Farm of the Kenana Sugar Scheme, Sudan. The experimental design was a split-plot arrangement with four replications. Nitrogen fertilizer was assigned to the main plots at four levels (0, 55, 110, and 164 kg/ha), while compost was applied to the subplots at four rates (0, 12, 24, and 36 t/ha). The results demonstrated that increasing nitrogen fertilizer rates significantly enhanced both the number of cane internodes and overall cane yield, while higher compost rates significantly improved internode number, and cane yield. Moreover, the combination of compost and nitrogen fertilizer further increased stalk population, number of internodes, and cane yield compared to their sole applications. The highest cane yield (172.0 t/ha) was recorded with the combined application of 36 t/ha compost and 164 kg/ha nitrogen. Based on the results of this study, it could be recommended that to obtain a high cane yield of sugarcane (variety Co6806), the crop should be fertilized by Nitrogen at the rate of 164 kg/ha and Compost at the rate of 36 tons/ha.*

***Keywords*— Sugarcane productivity, Compost application, Nitrogen fertilizer, Integrated nutrient management, Vertisol soils, Sustainable agriculture, Kenana Sugar Scheme, Organic and inorganic fertilizers.**

I. INTRODUCTION

Sugarcane (*Saccharum officinarum* L.) is a globally vital crop, primarily cultivated for sugar production and increasingly as a renewable source for bioethanol (Nair & Sachan 2022). Originating from New Guinea, sugarcane is now widely grown across tropical and subtropical regions between latitudes 35° North and South and at varying elevations from sea level to high altitudes (Moore et al. 2013). Adapted to warm, humid climates and various soil types, including sandy loams and heavy clays, sugarcane is a highly productive C4 plant with an efficient photosynthetic mechanism that supports rapid biomass accumulation (Mwasinga 2018); (Tew & Cobill 2008). The economic importance of sugarcane lies mainly in its accumulation of sucrose in the stalk internodes, which constitutes the raw material for sugar production. The chemical composition of sugarcane stalks varies according to variety, age, climate, soil conditions, and agronomic practices, directly affecting sugar extraction efficiency (James 2008). However, this high productivity often leads to significant soil nutrient depletion.

Sugarcane is generally cultivated under intensive monoculture systems with cycles of planting and ratooning, practices that demand consistent inorganic fertilizer applications to sustain soil fertility and achieve high yields (Kusumawati & Noviyanto 2025). Rising fertilizer costs and environmental concerns have drawn attention to the importance of recycling organic matter within agricultural systems to improve soil health and support sustainable crop production (Unagwu 2019). Incorporation of organic matter such as compost enhances soil physical and chemical properties, improving nutrient uptake and plant growth.

Global sugarcane cultivation generates substantial amounts of organic waste. Harvesting produces between 20 and 25 tons per hectare of trash mainly leaves and tops not sent for processing (Toharisman 1991). Additionally, sugar processing yields by-products like bagasse, filter mud, and molasses (Singh et al. 2021). For each ton of sugarcane processed, approximately 250 kg of bagasse and 36 kg of filter mud are generated, with filter mud comprising 1–7% of cane weight (Mena et al. 1985) ; (Salman et al. 2023). Traditionally, bagasse is used as fuel or raw material for other industries, while filter mud serves as a nutrient-rich organic amendment. Recycling these residues as compost improves soil fertility and physical characteristics and promotes sustainable farming (Iqbal 2018); (Stephen et al. 2024).

Application of compost derived from sugarcane residues enhances key soil chemical properties such as organic carbon, total nitrogen, available phosphorus, and potassium by stimulating microbial activity and nutrient cycling (Teshome et al. 2014). When integrated with inorganic nitrogen fertilizer, compost can further improve agronomic traits including cane height, stalk weight, and yield, as well as sugar quality parameters like Brix and sucrose content (Bekheet et al. 2018). Organic amendments also increase soil water holding capacity by 15–25% and microbial biomass carbon by 30–50%, contributing to annual increases in soil organic matter (Diacono & Montemurro 2011);(M. Sá et al. 2001). Although rich in organic matter (90–95%), compost generally has lower nutrient concentrations than commercial fertilizers and functions primarily as a soil conditioner (Khater 2015). Composting of residues such as filter mud, vinasse sludge, and animal wastes using methods like windrow composting produces stable, mature compost with optimal nutrient profiles (Meyer 2013);(Misra et al. 2003); (Nemet et al. 2021). The ideal compost quality is indicated by a carbon-to-nitrogen ratio between 10 and 25 (Sullivan & Miller 2001);(Gao et al. 2010); (Guo et al. 2012) ; (Mahapatra et al. 2022).

Sugarcane's high nitrogen demand (200–300 kg N/ha) has led to extensive chemical fertilizer use, yet nitrogen use efficiency remains low (30–50%), causing environmental issues such as groundwater nitrate contamination and greenhouse gas emissions (Otto et al. 2016);(Thorburn et al. 2017);(Chen et al. 2022) ;(Van Beneden et al. 2010). Nitrogen is vital for tillering, early crop population, and photosynthetic efficiency since leaf nitrogen content influences photosynthesis rates (Otto et al. 2014);(Bassi et al. 2018). Studies show that integrating nitrogen fertilizer with compost improves yield components such as stalk girth, weight, and sugar yield; for instance, 46 kg N/ha combined with 15 t/ha compost produced superior cane and sugar yields on clay soils compared to sole applications (Zeng et al. 2020);(Sopandie et al. 2011).

Long-term sugarcane monoculture leads to soil degradation characterized by 30–40% loss of original soil organic carbon over 20 years, adversely affecting yield potential (up to 35% productivity reduction) and processing quality (2–4% sucrose loss) (Bottinelli et al. 2020);(Obour et al. 2017);(Verma et al. 2024). The industry faces ongoing challenges including biotic and abiotic stresses, high production costs, post-harvest losses, and low sugar recovery (Bhatt 2020). These factors underscore the need for sustainable cultivation practices and balanced nutrient management combining organic and inorganic inputs to maintain productivity and environmental sustainability (Chattopadhyay 2012).

In Sudan, sugarcane yields average around 60 t/ha, lower than many irrigated regions globally (Ibrahim 2020). Given the strategic importance of sugar production for domestic consumption and export, sustainable practices are essential. The Kenana Sugar Scheme, located on Vertisol soils of the White Nile, features heavy clay soils with high smectite content, significant shrink-swell behaviour, moderate fertility with low nitrogen and organic matter, and cation exchange capacity and electrical conductivity below 2 mS/cm³ (Emam & Musa 2011); (Ganawa & Kheiralla 2011).

Mechanization and exclusive reliance on chemical fertilizers have contributed to soil compaction and degradation (Pankhurst et al. 2003); (Batey 2009) ; (Iqbal 2018). There is limited research on integrated use of compost and nitrogen fertilizer in this context, making investigation necessary to optimize both yield and soil health.

Accordingly, a research project was initiated in 2023/2024 to investigate the effects of compost application on sugarcane production under the conditions of the Kenana Sugarcane Estate. For the above mention reasons the main objective of this research is:

Main objectives:

- To evaluate the effects of compost and nitrogen fertilizer applications on the productivity of sugarcane at the Kenana Sugar Scheme.

Specific objectives:

- To determine the optimum application rates of compost and nitrogen fertilizer to achieve the highest yield of sugarcane.

II. LITERATURE REVIEW

2.1 Compost and Soil Fertility:

Compost application improves soil organic carbon, microbial biomass, nutrient availability, and physical properties such as water retention and aggregation (Teshome et al. 2014); (Diacono & Montemurro 2011). Compost from bagasse and filter mud enriches nutrients and enhances microbial activity, facilitating sustainable nutrient cycling (Rahmad et al. 2019) ; (Arefin et al. 2022). Improved soil quality translates to increased crop growth and yield in sugarcane (Iqbal 2018); (Aguilar-Paredes et al. 2023) as the primary center of genetic diversity for sugarcane (Dulfer et al. 2022).

2.2 Nitrogen Fertilization in Sugarcane:

Nitrogen critically influences tillering, stalk elongation, dry matter accumulation, and yield (Sharma et al. 2013); (Mischan et al. 2011). However, excessive nitrogen can delay maturity and reduce sugar quality, affecting purity and sucrose concentration (Berding et al. 2005);(Mudassar et al. 2022). Balanced nitrogen management with organic amendments reduces environmental impact while maximizing productivity (Yusuf et al. 2018; Liu et al. 2018).

2.3 Integration of Compost and Nitrogen:

Combining compost with nitrogen fertilizer enhances nitrogen use efficiency, soil microbial activity, and overall crop performance (Sasy & Abu-Ellail 2021); (Bebber & Richards 2022). Compost supplies slow-release nutrients and improves soil structure, while nitrogen supports rapid vegetative growth. This integration aligns with sustainable agricultural goals by reducing mineral fertilizer dependence and improving soil health (Sayara et al. 2020);(Wright et al. 2022).

III. MATERIALS AND METHODS

3.1 Experimental Site Description:

The experiment was conducted at the Research and Development Farm of the Kenana Sugar Scheme, Sudan, during the 2023/2024 growing season. Kenana is geographically situated between the White Nile and Blue Nile rivers, at approximately 33° E longitude and 13° N latitude, with an elevation of 410 meters above sea level (Ibrahim & Workneh 2023). The site is located about 330 km south of Khartoum, the capital city of Sudan, and 30 km southeast of Rabak Town (Ahmed & others 2016). The climate of the area is characterized as tropical aridic, with a distinct summer rainy season lasting approximately five months, from June to October, peaking in August. The average annual rainfall for the two seasons under study was 379 mm, although rainfall varies considerably from year to year. Temperature extremes range from a mean maximum of 42 °C in May to a minimum of 13.7 °C in January. Relative humidity fluctuates between 20.5% and 79.8%. The soil at the experimental site is classified as a brown, heavy clay Vertisol. The top 60 cm soil profile consists of cracking clay with a clay content ranging from 40% to 60% (Mohamed 2018). Soil pH values range from 7.50 to 8.50 (Antille et al. 2016). More than 90% of the upper soil horizon exhibits electrical conductivity values below 3 mS/cm³. Extractable sodium percentage (ESP) ranges between 510 and 770 ppm (MOHAMMED 2006).

3.2 Experimental Layout Design and Treatments:

This study examines the individual and interactive effects of compost and nitrogen fertilization on various growth, yield of sugarcane. The experimental material consisted of four nitrogen levels (0, 55, 110, and 164 kg/ha) and four compost levels (0, 12, 24, and 36 tons/ha). The experiment employed a split-plot design (factorial arrangement) with four replications. Nitrogen levels were assigned to the main plots, and compost levels to the subplots. The total plot area was 60 m² (plot size: 4 furrows, each 10 meters long and 1.5 meters wide). The test variety used was Co6806. Statistical analysis was conducted using Duncan's Multiple Range Test (DMRT).

3.3 Cultural Practices:

3.3.1 Fertilizer and Compost Application:

Compost was applied as a single dose and uniformly spread along the ridges at the time of planting. Nitrogen fertilizer was also applied as a single dose at planting. All agronomic practices including irrigation, weeding, and other management operations were carried out uniformly across all experimental plots, following the standard protocols of the Sugar Estate.

The compost used in this study was produced by the Kenana Sugar Company using the windrow composting method. Windrow composting involves piling organic materials, such as agricultural and industrial byproducts, into long rows (windrows) that are regularly turned to ensure adequate aeration, moisture distribution, and temperature control. This aerobic process accelerates the decomposition of organic matter, reduces Odor, and minimizes the risk of soil and water pollution. The temperature of the windrows is monitored to ensure the process passes through the necessary mesophilic and thermophilic phases, which are critical for pathogen reduction and compost stabilization.

Before field application, the maturity of the compost was assessed by evaluating its odor and colour, which are reliable indicators of stability and readiness for use. Additional parameters, such as the C/N ratio and cation exchange capacity, may also be used to confirm compost maturity and biological stability.

The compost formula consisted of organic raw materials with balanced nutrient content, specifically tailored for agricultural use by the Kenana Sugar Company. The composition was as follows: filter mud (45–50%), green cane trash (25–30%), cow manure (8–10%), and poultry manure (4–5%), and vinasse sludge (3–5%). This blend provides a rich source of macro- and micronutrients, improves soil structure, and enhances water-holding capacity, contributing to long-term soil fertility and sustainability.

3.3.2 Land Preparation:

Land under continuous sugarcane cultivation was used. The stubble of the previous crop was uprooted using a disc plow in April, and the land was then left fallow during the summer months and rainy period. When it was dry, it was deeply plowed using the same disc plow, disk harrowed by a wide level disc, levelled using a planer and ridged at 1.5 meters spacing using a ridger.

3.3.3 Planting Method:

Planting was carried out using the continuous double-set furrow method. Seed cane was obtained from ten-month-old stalks of the plant crop, which were cut into short setts, each containing three buds. Following fertilizer application, these setts were uniformly placed in the furrows at a rate of 264 setts per plot. To protect the setts from termite damage, the insecticide Regent was applied directly by spraying at a rate of 2.38 L/ha. After treatment, the setts were manually covered with soil and irrigated immediately to ensure proper establishment.

3.3.4 Weed Control:

A combination of the herbicides Stomp (pendimethalin) and Gezaprim (atrazine) was applied as a pre-emergence treatment, following commercial recommendations, just prior to the second irrigation. The application rates were 1.43 L/ha for Stomp and 1.79 kg/ha for Gezaprim. To ensure effective weed control, plots were maintained weed-free by supplementary hand weeding whenever necessary throughout the growing season.

3.3.5 Hilling-Up Practice:

Hilling up of the plant rows was performed three months after planting. This involved raising the soil around the cane plants by employing the split ridging technique to cover the furrows in which the cane was planted. This practice helps improve soil aeration, moisture retention, and supports healthy crop growth.

3.3.6 Irrigation Management:

During the germination phase, setts were irrigated at 12-day intervals to ensure optimal moisture for sprouting. After the completion of germination, subsequent irrigations were applied as needed based on crop requirements and prevailing environmental conditions.

3.3.7 Pre-Harvest Drying Off:

Prior to each harvest, irrigation was withheld from the plots scheduled for harvesting for a period of one month to allow the fields to dry adequately. This pre-harvest drying off facilitates easier harvesting and improves cane quality.

3.3.8 Harvesting Procedure:

The harvested area for each plot was 30 m², consisting of two rows, each 10 meters in length and 1.5 meters in width. Harvesting was conducted manually. Stalks were cut precisely at the soil surface to maximize yield and ensure uniformity. After cutting, all stalks were thoroughly cleaned by removing leaves and tops, ensuring that only the cane stalks were retained for subsequent analysis and yield determination. This standardized harvesting method ensures accurate assessment of productivity and quality parameters across all experimental plots.

3.4 Collection of Data for Cane Yield Components:

A random sample of 10 stalks was collected from each plot for yield component analysis. These stalks were weighed and subsequently used to determine stalk height, stalk thickness (diameter), and the number of internodes per stalk. This sampling method ensured the accurate and representative assessment of the key yield parameters for each treatment.

3.4.1 Stalk Height (m):

Stalk height was measured for each sampled stalk from the base to the top visible dewlap (TVD) using a measuring tape. The measurements were then averaged and expressed as the mean stalk height in meters for each plot.

3.4.2 Stalk Thickness (Diameter) (cm):

Stalk thickness was measured at the middle internode of each sampled stalk using a Vernier caliper. The measurements were averaged and expressed as mean stalk diameter in centimeters for each plot.

3.4.3 Number of Internodes per Stalk:

The number of internodes was counted for each sampled stalk, and the results were expressed as the average number of internodes per stalk for each plot.

3.4.4 Stalk Weight (kg):

A random sample of 10 stalks was collected from each plot and weighed. The results were expressed as the average stalk weight in kilograms per stalk for each plot.

3.4.5 Stalk Number (Population) (1000/ha):

The number of millable stalks in each harvested plot was counted and the data were converted to express stalk population as the number of millable stalks per hectare (in thousands). This parameter provides an estimate of cane population density, which is a key component of yield assessment.

3.4.6 Final Cane Yield (ton/ha):

The crop was harvested in February 2024 when it reached 13 months of age. All millable cane from the two inner rows of each plot (30 m²) was manually cut at the soil surface and arranged in bundles for weighing. The weights of the samples taken for other observations were also included in the total yield calculation. The harvested millable stalks from each plot were weighed using a portable spring balance (MD Totco™) attached to a tractor-mounted grab crane. The total weight was then converted to tons per hectare to determine the final cane yield for each plot.

3.5 Data Statistical Analysis:

The data were analyzed using standard analysis of variance (ANOVA) appropriate for the split-plot design, utilizing the MSTATC statistical software package. Means found to be significant were separated using Duncan's Multiple Range Test (DMRT) as described by Gomez and Gomez (1976). This approach ensured robust evaluation of treatment effects and reliable comparison among means.

IV. RESULTS AND DISCUSSION

4.1 Yield components:

4.1.1 Effect of Compost and Nitrogen fertilizer and their interaction on cane Height (cm):

Table (1) shows the effect of compost and nitrogen fertilizer levels, and their interaction, on cane Height. The results indicate that nitrogen fertilizer application had no significant effect on stalk height across treatments, with values ranging from 267.6 to 269.9 cm. These findings are consistent with (Saleem et al. 2023), who reported that sugarcane height is primarily governed by genetic factors rather than nutrient inputs under well-fertilized conditions. (Desalegn et al. 2023) also found that varying nitrogen fertilizer rates did not significantly influence plant height in sugarcane.

Compost application levels likewise exhibited a non-significant effect on stalk height, with mean values ranging from 266.1 to 273.4 cm across treatments. This observation aligns with previous research suggesting that compost may not always provide immediately available nitrogen for rapid crop growth, particularly when the nitrogen present is largely in organic form and its mineralization does not coincide with crop demand (Maucieri et al. 2019).

The interaction effect between compost and nitrogen fertilizer levels on cane height was also found to be non-significant. These results suggest that, under the conditions of this study, neither compost nor nitrogen fertilizer application, nor their interaction, had a significant impact on cane height, highlighting the overriding influence of genetic and environmental factors on this trait.

TABLE 1
EFFECT OF COMPOST AND NITROGEN FERTILIZER AND THEIR INTERACTION ON CANE HEIGHT (CM).

Compost (ton/ha)	Nitrogen(kg/ha)				Mean
	0	55	110	164	
0	280.8 a	270.5 ab	272.5 ab	270.0 ab	273.4 A
12	262.0 b	269.8 ab	270.5 ab	264.3 ab	266.6 A
24	270.3 ab	273.8 ab	268.3 ab	275.0 ab	271.8 A
36	257.3 b	268.3 ab	268.5 ab	270.5 ab	266.1 A
Mean	267.6 A	270.6 A	269.9 A	269.9 A	
SE ± for Nitrogen	7.1				
SE ± for Compost	4.12				
SE ± for Interaction	8.3				
CV(%)	6.1				

Means followed by the same letter (s) are not significantly different according to Duncan's Multiple Range Test (DMRT).

4.1.2 Effect of Compost and Nitrogen fertilizer and their interaction on internodes number:

Table (2) presents the effect of compost and nitrogen fertilizer levels, as well as their interaction, on the number of internodes in sugarcane. The results indicate that both compost and nitrogen fertilizer applications, individually and in combination, had significant effects on internode number. Increasing nitrogen fertilizer rates from 0 to 164 kg/ha resulted in a significant increase in the number of internodes. The highest mean value (25.7) was observed at the 164 kg/ha nitrogen level, while the lowest mean (24.5) was recorded at 0 kg/ha nitrogen. These findings are consistent with (Sharma et al. 2013), who reported that nitrogen fertilization promotes internode formation and elongation, with increases of 12–18% in internode numbers at optimal nitrogen rates.

Compost application levels also had a significant effect on internode number. Increasing the compost rate from 0 to 36 t/ha led to a significant increase in the number of internodes. The highest mean (26.4) was recorded at 36 t/ha compost, which was significantly greater than all other compost levels, while the lowest mean (23.6) was observed in the control (0 t/ha compost). These results are in agreement with (Sousa & Grichar 2024), who demonstrated that compost application promotes tillering and node development in grasses such as sugarcane.

The interaction effect between compost and nitrogen fertilizer was also significant, as indicated by the standard error for interaction (SE = 2.8). The greatest number of internodes (27.0) was recorded with the combined application of 36 t/ha compost and 164 kg/ha nitrogen, whereas the lowest value (23.0) was observed with no compost and no nitrogen. This significant interaction can be attributed to the role of compost in enhancing nitrogen availability, which in turn directly affects meristematic activity and internode development.

TABLE 2
EFFECT OF COMPOST AND NITROGEN FERTILIZER AND THEIR INTERACTION ON INTERNODES NUMBER

Compost (ton/ha)		Nitrogen(kg/ha)			Mean
	0	55	110	164	
0	23.0 d	23.0 d	24.0 c	24.3 c	23.6 D
12	24.0 c	24.3 c	25.0 b	25.5 b	24.7 C
24	25.0 b	25.0 b	25.0 b	26.0 a	25.3 B
36	26.0 a	26.0 a	26.8 a	27.0 a	26.4 A
Mean	24.5 C	24.6 C	25.2 B	25.7 A	
SE ± for Nitrogen	0.3				
SE ± for Compost	0.6				
SE ± for Interaction	2.8				
CV(%)	2.5				

Means followed by the same letter (s) are not significantly different according to Duncan's Multiple Range Test (DMRT).

4.1.3 Effect of Compost and Nitrogen and their interaction on stalk thickness (mm):

Table (3) presents the effects of compost and nitrogen fertilizer levels, as well as their interaction, on cane girth (stalk thickness). The results showed that neither compost nor nitrogen nor their interaction significantly affected stalk thickness. Nitrogen fertilizer application did not significantly influence cane girth. These findings are in agreement with (Pei Tukuljac et al. 2023), who reported that nitrogen fertilizer application rates had no significant effect on cane girth in their study on sugarcane productivity and sugar yield improvement.

Compost application levels also had a non-significant effect on cane girth. This finding is consistent with (Desalegn et al. 2023), who found that compost application did not significantly affect internode number or stalk girth under certain soil fertility and nutrient availability conditions.

The interaction between compost and nitrogen fertilizer levels was also not significant for cane girth.

TABLE 3
EFFECT OF COMPOST AND NITROGEN FERTILIZER AND THEIR INTERACTION ON STALK THICKNESS (mm)

Compost (ton/ha)	Nitrogen(kg/ha)				Mean
	0	55	110	164	
0	25.3 a	26.0 a	23.8 a	24.5 a	24.9 A
12	24.3 a	24.8 a	25.3 a	25.5 a	24.9 A
24	25.0 a	26.0 a	25.8 a	25.0 a	25.4 A
36	25.5 a	25.0 a	24.3 a	25.3 a	25.0 A
Mean	25.0 A	25.4 A	24.8 A	25.1 A	
SE ± for Nitrogen	0.32				
SE ± for Compost	0.29				
SE ± for Interaction	0.65				
CV(%)	5.2				

Means followed by the same letter (s) are not significantly different according to Duncan's Multiple Range Test (DMRT).

4.1.4 Effect of Compost and Nitrogen fertilizer and their interaction on Stalk Population (1000 plant/ha):

Table (4) shows the effect of compost and nitrogen fertilizer levels, as well as their interaction, on cane population density. The results indicate that nitrogen fertilizer alone did not have a significant effect on cane population, with stalk counts ranging from 107,000 to 151,000 plants per hectare across treatments. This finding aligns with the conclusions of (Balaganesh et al. 2020) and (Nawaz et al. 2017), who emphasized that stalk population is primarily influenced by planting density, seed cane quality, and initial establishment conditions rather than fertilization.

Compost application levels also exhibited a non-significant effect on cane population. This observation is consistent with previous studies indicating that although compost improves soil fertility and plant vigor, it does not necessarily lead to an increase in the number of cane stalks per unit area. For example, (Balaganesh et al. 2020) and (Otto et al. 2016) found that in soils with moderate fertility, the application of compost or other organic amendments did not significantly increase cane population.

The interaction between compost and nitrogen fertilizer levels had a significant effect on stalk population. The highest stalk count (151,000 plants/ha) was achieved with the combined application of 36 tons/ha compost and 110 kg/ha nitrogen.

TABLE 4
EFFECT OF COMPOST AND NITROGEN FERTILIZER AND THEIR INTERACTION ON STALK POPULATION (1000 PLANT/HA)

Compost (ton/ha)	Nitrogen(kg/ha)				Mean
	0	55	110	164	
0	119 abc	117 abc	126 abc	107 c	117 A
12	140 abc	123 abc	126 abc	129 abc	129 A
24	128 abc	133 abc	145 ab	117 abc	131 A
36	113 bc	118 abc	**151 a**	133 abc	129 A
Mean	125 A	123 A	137 A	122 A	
SE ± for Nitrogen	4.9				
SE ± for Compost	5.8				
SE ± for Interaction	9.9				
CV(%)	15.6				

Means followed by the same letter (s) are not significantly different according to Duncan's Multiple Range Test (DMRT).

4.1.5 Effect of Compost and Nitrogen fertilizer and their interaction on cane yield (ton/ha):

The effect of compost and nitrogen fertilizer levels, as well as their interaction, on sugarcane yield are shown in Table (5). The results indicate that both compost and nitrogen fertilizer, individually and in combination, had significant effects on cane yield. Nitrogen fertilizer application significantly increased cane yield, with the highest yield (153.9 t/ha) recorded at 110 kg N/ha. This finding is consistent with (Mudassar et al. 2022), who reported that higher nitrogen rates significantly enhance both cane and sugar yields, reflecting the strong positive influence of nitrogen on sugarcane productivity.

Compost application also had a significant effect on cane yield. The highest yield (163.9 t/ha) was achieved with the application of 36 t/ha compost. This result aligns with (Teshome et al. 2014), who found that compost improved soil chemical properties, such as organic carbon and total nitrogen, thereby contributing to yield increases.

The interaction between compost and nitrogen fertilizer levels had a highly significant effect on cane yield. The highest yield (172.0 t/ha) was obtained with the combined application of 36 t/ha compost and 164 kg/ha nitrogen, while the lowest yield (119.1 t/ha) was observed in the control treatment.

TABLE 5
EFFECT OF COMPOST AND NITROGEN FERTILIZER AND THEIR INTERACTION ON CANE YIELD (TON/HA)

Compost (ton/ha)	Nitrogen(kg/ha)				Mean
	0	55	110	164	
0	119.2 c	142.3 abc	126.2 bc	119.1 c	126.7 D
12	139.6 abc	144.9 abc	161.4 a	124.7 bc	142.6 C
24	155.7 ab	151.6 abc	163.7 a	145.7 abc	154.2 B
36	159.9 a	159.6 a	164.1 a	172.0 a	163.9 A
Mean	143.6 B	149.6 B	153.9 A	140.4 B	
SE ± for Nitrogen	3.3				
SE ± for Compost	5.5				
SE ± for Interaction	6.6				
CV(%)	9.0				

Means followed by the same letter (s) are not significantly different according to Duncan's Multiple Range Test (DMRT).

V. CONCLUSIONS AND RECOMMENDATION

5.1 Conclusion:

From this study it could be concluded that:

1) Compost application showed dominant effects (29.4% increase) over nitrogen.

2) Nitrogen effects are optimized and variable across parameters.
3) Increasing nitrogen fertilizer levels significantly increased the number of internodes and cane yield.
4) Increasing compost application levels significantly increased the number of internodes and cane yield.
5) There were significant interactions in the stalk population, number of internodes, and cane yield.
6) The highest cane yield (172.0 tons/ha) was obtained when 164 kg/ha of nitrogen and 36 tons/ha of Compost were applied.

This experiment demonstrates that the combined application of compost and nitrogen fertilizer is a more effective strategy for sustainable sugarcane production. Achieving a yield of 172.0 tons per hectare with 36 tons of compost and 164 kg of nitrogen input represents a paradigm shift toward combination fertilization systems. The findings suggest that a fundamental combination of "nitrogen-centric" and "organic matter-centric" sugarcane nutrition strategies may be warranted. Therefore, a transformation to compound fertilizer recommendations is needed and opens new possibilities for sustainable production intensification.

5.2 Recommendations:

Based on the results of this study, it could be recommended that to obtain a high cane yield of sugarcane (variety Co6806), the crop should be fertilized by Nitrogen at the rate of 164 kg/ha and Compost at the rate of 36 tons/ha.

REFERENCES

[1] Aguilar-Paredes, A. et al., 2023. Microbial community in the composting process and its positive impact on the soil biota in sustainable agriculture. *Agronomy*, 13(2), p.542.

[2] Ahmed, N.S.E. & others, 2016. *Economic Analysis of the Competitiveness and Cropping Pattern of Small-Scale Farms in the Rain-Fed Sector of Gadarif State-Sudan*. Sudan University of Science and Technology.

[3] Antille, D.L., Bennett, J.M. & Jensen, T.A., 2016. Soil compaction and controlled traffic considerations in Australian cotton-farming systems. *Crop and Pasture Science*, 67(1), pp.1–28.

[4] Arefin, M.S. et al., 2022. Integrated nutrient management improves productivity and quality of sugarcane (saccharum officinarum L.). *Phyton*, 91(2), p.439.

[5] Balaganesh, P. et al., 2020. Evaluation of sugarcane and soil quality amended by sewage sludge derived compost and chemical fertilizer. *Nature Environment and Pollution Technology*, 19(4), pp.1737–1741.

[6] Bassi, D., Menossi, M. & Mattiello, L., 2018. Nitrogen supply influences photosynthesis establishment along the sugarcane leaf. *Scientific reports*, 8(1), p.2327.

[7] Batey, T., 2009. Soil compaction and soil management–a review. *Soil use and management*, 25(4), pp.335–345.

[8] Bebber, D.P. & Richards, V.R., 2022. A meta-analysis of the effect of organic and mineral fertilizers on soil microbial diversity. *Applied Soil Ecology*, 175, p.104450.

[9] Bekheet, M.A., Gadallah, A.F. & Khalifa, Y.A., 2018. Enhancement of yield and quality of sugarcane by applied nitrogen, phosphorus and filter cake. *Egyptian Journal of Agronomy*, 40(3), pp.207–221.

[10] Van Beneden, S. et al., 2010. Microbial populations involved in the suppression of Rhizoctonia solani AG1-1B by lignin incorporation in soil. *Soil Biology and Biochemistry*, 42(8), pp.1268–1274.

[11] Berding, N. et al., 2005. Agronomic impact of sucker development in sugarcane under different environmental conditions. *Field Crops Research*, 92(2-3), pp.203–217.

[12] Bhatt, R., 2020. Resources management for sustainable sugarcane production. *Resources use efficiency in agriculture*, pp.647–693.

[13] Bottinelli, N. et al., 2020. An explicit definition of earthworm ecological categories–Marcel Bouché's triangle revisited. *Geoderma*, 372, p.114361.

[14] Chattopadhyay, G.N., 2012. Use of vermicomposting biotechnology for recycling organic wastes in agriculture. *International Journal of Recycling of Organic Waste in Agriculture*, 1, pp.1–6.

[15] Chen, S.-K., Lee, Y.-Y. & Liao, T.-L., 2022. Assessment of Ammonium–N and Nitrate–N Contamination of Shallow Groundwater in a Complex Agricultural Region, Central Western Taiwan. *Water*, 14(13), p.2130.

[16] Desalegn, B. et al., 2023. Sugarcane productivity and sugar yield improvement: Selecting variety, nitrogen fertilizer rate, and bioregulator as a first-line treatment. *Heliyon*, 9(4).

[17] Diacono, M. & Montemurro, F., 2011. Long-term effects of organic amendments on soil fertility. *Sustainable agriculture volume 2*, pp.761–786.

[18] Dulfer, H.E. et al., 2022. Reconstructing the advance and retreat dynamics of the central sector of the last Cordilleran Ice Sheet. *Quaternary Science Reviews*, 284, p.107465.

[19] Emam, A.A. & Musa, O.M., 2011. The competitiveness of sugar cane production: A study of Kenana Sugar Company, Sudan. *Journal of Agricultural Science*, 3(3), p.202.

[20] Ganawa, E. & Kheiralla, A., 2011. Adoption of GIS, GPS and RS Techniques in the Sudanese Sugarcane Industry: Part 1-Kenana Base Map Establishment. *Khartoum University Engineering Journal*, 1(1).

[21] Gao, M. et al., 2010. Evaluation of stability and maturity during forced-aeration composting of chicken manure and sawdust at different C/N ratios. *Chemosphere*, 78(5), pp.614–619.

[22] Guo, R. et al., 2012. Effect of aeration rate, C/N ratio and moisture content on the stability and maturity of compost. *Bioresource technology*, 112, pp.171–178.

[23] Ibrahim, T., 2020. *Assessment of the Sudane Ses' Sugar Industry Life Cycle and Technical Factors Influencing the Productivity*. University of KwaZulu-Natal Pietermaritzburg.

[24] Ibrahim, T.S.T. & Workneh, T.S., 2023. The environmental impact of the sugar industry waste in Sudan. *Environmental monitoring and assessment*, 195(7), p.870.

[25] Iqbal, I., 2018. Effect of sugarcane litter compost on soil compaction. *International Journal of Agriculture System*, 6(1), pp.35–44.

[26] James, G., 2008. *Sugarcane*, John Wiley & Sons.

[27] Khater, E.-S.G., 2015. Some physical and chemical properties of compost. *Int. J. Waste Resour*, 5(1), pp.72–79.

[28] Kusumawati, A. & Noviyanto, A., 2025. Long-term effects of sugarcane monoculture on soil pedomorphology and physicochemical properties in tropical agroecosystems. *Plant, Soil & Environment*, 71(3).

[29] M. Sá, J.C. de et al., 2001. Organic matter dynamics and carbon sequestration rates for a tillage chronosequence in a Brazilian Oxisol. *Soil Science Society of America Journal*, 65(5), pp.1486–1499.

[30] Mahapatra, S., Ali, M.H. & Samal, K., 2022. Assessment of compost maturity-stability indices and recent development of composting bin. *Energy Nexus*, 6, p.100062.

[31] Maucieri, C., Barco, A. & Borin, M., 2019. Compost as a substitute for mineral N fertilization? Effects on crops, soil and N leaching. *Agronomy*, 9(4), p.193.

[32] Mena, A. et al., 1985. The Utilization of Sugar Cane by-products as substitutes for cereal in animal feed.

[33] Meyer, J., 2013. The soil and its environment. *Good Management Practices for the Cane Sugar Industry. International Finance Corporation, Berlin, Germany*, pp.73–116.

[34] Mischan, M.M., Pinho, S.Z. de & Carvalho, L.R. de, 2011. Determination of a point sufficiently close to the asymptote in nonlinear growth functions. *Scientia Agricola*, 68, pp.109–114.

[35] Misra, R., Roy, R. & Hiraoka, H., 2003. *On-farm composting methods*, Rome, Italy: UN-FAO.

[36] Mohamed, E.A.G.A., 2018. *Determination of Crop Water Requirements and Irrigation Scheduling of Aerobic Rice (Oryza sativa L.), Gezira State, Sudan*. University of Gezira.

[37] MOHAMMED, R.A.A.A., 2006. *SOCIO-ECONOMIC EFFECTS OF REHABLITATED DESERTIFIED AGRICULTURAL TENANCIES OF NORTH WESTERN PARTS OF THE GEZIRA SCHEME*. University of Khartoum.

[38] Moore, P.H., Paterson, A.H. & Tew, T., 2013. Sugarcane: the crop, the plant, and domestication. *Sugarcane: physiology, biochemistry, and functional biology*, pp.1–17.

[39] Mudassar, M.A. et al., 2022. Response of Sugarcane to Varying Nitrogen Rate and Application Timings Under Semi-Arid Climate. *Journal of Applied Research in Plant Sciences*, 3(02), pp.248–259.

[40] Mwasinga, G., 2018. *Effects of nitrogen fertilizer on yield and quality of introduced sugarcane (Saccharum Officinarum l.) varieties in commercial fields at Kilombero, Morogoro Region*. Sokoine University of Agriculture.

[41] Nair, P.N. & Sachan, H., 2022. The Improvement of sugarcane (Saccharum officinarum L.) for sugar, ethanol and biofuel production through innovative biotechnology: A perspective view on its scope, importance & challenges. In *Omics Approaches for Sugarcane Crop Improvement*. CRC Press, pp. 233–249.

[42] Nawaz, M. et al., 2017. Assessment of compost as nutrient supplement for spring planted sugarcane (Saccharum officinarum L.). *JAPS: Journal of Animal & Plant Sciences*, 27(1).

[43] Nemet, F., Peri, K. & Loncari, Z., 2021. Microbiological activities in the composting process–A review. *COLUMELLA–Journal of Agricultural and Environmental Sciences*, 8(2), pp.41–53.

[44] Obour, A.K. et al., 2017. Changes in soil surface chemistry after fifty years of tillage and nitrogen fertilization. *Geoderma*, 308, pp.46–53.

[45] Otto, R. et al., 2016. Nitrogen use efficiency for sugarcane-biofuel production: what is next? *Bioenergy Research*, 9, pp.1272–1289.

[46] Otto, R. et al., 2014. The role of nitrogen fertilizers in sugarcane root biomass under field conditions. *Agricultural Sciences*, 5(14), pp.1527–1538.

[47] Pankhurst, C. et al., 2003. Management practices to improve soil health and reduce the effects of detrimental soil biota associated with yield decline of sugarcane in Queensland, Australia. *Soil and Tillage Research*, 72(2), pp.125–137.

[48] Pei Tukuljac, L. et al., 2023. Biosorption of Na+, K+ and Ca2+ from alkalized sugar juice by unmodified pressed sugar beet pulp in closed-loop column system. *Sugar Tech*, 25(4), pp.766–776.

[49] Rahmad, L.A., Kuswinanti, T. & Musa, Y., 2019. The effect of sugarcane bagasse and filter mud compost fertilizer and manure application on the growth and production of sugarcane. *Int. J Sci. Res. & Tech*, 6(6), pp.338–345.

[50] Saleem, B. et al., 2023. Evaluation of sugarcane promising clones based on the morphophysiological traits developed from fuzz. *PeerJ*, 11, p.e15646.

[51] Salman, M. et al., 2023. Composting sugarcane filter mud with different sources differently benefits sweet maize. *Agronomy*, 13(3), p.748.

[52] Sasy, A.H. & Abu-Ellail, F.F., 2021. Phenotypic Correlations and Integration of Nitrogen, Potassium and Press Mud Fertilizers in Relation to Sugarcane Yield and Quality. *Alexandria Science Exchange Journal*, 42(JANUARY-MARCH), pp.37–48.

[53] Sayara, T. et al., 2020. Recycling of organic wastes through composting: Process performance and compost application in agriculture. *Agronomy*, 10(11), p.1838.

[54] Sharma, A. et al., 2013. Analyzing rainfall effects for sustainable rainfed maize productivity in foothills of Northwest Himalayas. *Field Crops Research*, 145, pp.96–105.

[55] Singh, S.P. et al., 2021. Sugarcane wastes into commercial products: Processing methods, production optimization and challenges. *Journal of Cleaner Production*, 328, p.129453.

[56] Sopandie, D. et al., 2011. Application of Filter Cake on Growth of Upland Sugarcanes. *Jurnal Agronomi Indonesia (Indonesian Journal of Agronomy)*, 39(2).

[57] Sousa, R.N. de & Grichar, W.J., 2024. *Strategic Tillage and Soil Management: New Perspectives*, BoD–Books on Demand.

[58] Stephen, G.S. et al., 2024. Harnessing the potential of sugarcane-based liquid byproducts—molasses and spentwash (vinasse) for enhanced soil health and environmental quality. A systematic review. *Frontiers in Agronomy*, 6, p.1358076.

[59] Sullivan, D.M. & Miller, R.O., 2001. Compost quality attributes, measurements and variability.

[60] Teshome, Z., Abejehu, G. & Hagos, H., 2014. Effect of nitrogen and compost on sugarcane (Saccharum Officinarum L) at Metahara sugarcane plantation. *Advances in Crop Science and Technology*, 2(5), pp.153–156.

[61] Tew, T.L. & Cobill, R.M., 2008. Genetic improvement of sugarcane (Saccharum spp.) as an energy crop. In *Genetic improvement of bioenergy crops*. Springer, pp. 273–294.

[62] Thorburn, P.J. et al., 2017. Prioritizing crop management to increase nitrogen use efficiency in Australian sugarcane crops. *Frontiers in Plant Science*, 8, p.1504.

[63] Toharisman, A., 1991. Sustainable Sugar Cane Management. *Indonesian Research Centre of Sugarcane Plantation (P3GI)*.

[64] Unagwu, B., 2019. Organic amendments applied to a degraded soil: Short term effects on soil quality indicators. *African Journal of Agricultural Research*, 14(4), pp.218–225.

[65] Verma, K.K. et al., 2024. Sugarcane Cultivation and Management: Challenges and Opportunities.

[66] Wright, J., Kenner, S. & Lingwall, B., 2022. Utilization of compost as a soil amendment to increase soil health and to improve crop yields. *Open Journal of Soil Science*, 12(6), pp.216–224.

[67] Zeng, X.-P. et al., 2020. Long-term effects of different nitrogen levels on growth, yield, and quality in sugarcane. *Agronomy*, 10(3), p.35.

The Post-Harvest Losses: The Consequences for Africa

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Abstract—

Introduction: *The Food and Agricultural Organization predicts that about 1.3 billion tonnes of food are globally wasted or lost per year. This is equivalent to 30% of food produced for human consumption for the same period. Some reports have estimated that this lost or wasted food can be used to feed 1.6 billion people every year.*

Problem Statement: *Global food waste is a far-reaching problem with tremendous financial, ethical and environmental costs. The amount of food lost or wasted costs US$2.6 trillion annually and is more than enough to feed about 815 million hungry people in the world four times over.*

Methodology: *The study is mainly qualitative with some quantitative in scope making use of secondary data (literature from journals, working papers, unpublished theses, publications from government, World Bank and similar institutions) and global agribusiness industry.*

Results: *The review found out that, via meta-analysis, evidence of post-harvest losses in Africa is spotty and quantitative estimates are often derived from inadequate datasets. The major reason for many post-harvest losses estimates is weak assessment methodologies. The world's increasing population and demand for food, reducing food loss and waste is one of the challenges globally. Food loss and waste have significant negative food-security, economic and environmental impacts. The value of annual food loss and waste globally is about US$1 trillion and one billion tonnes in quantity.*

Conclusion: *Although reduction of post-harvest food losses is a critical component of ensuring future global food security, however, production resources including land, water and energy are at the moment limited and inelastic.*

Keywords— Food Security; Post-harvest Losses and Waste; Supply Chain; Qualitative and Quantitative Losses.

I. INTRODUCTION

Current world population (8.2 billion June 2025) is expected to reach 9.7 billion by 2050, withAfrica contributing more than half of that increase, further adding to global food security concerns [1]. This increase translates into 33% more human mouths to feed with the greatest demand growth in the poor communities of the world, Africa for example. According to [2], food supplies would need to increase by 70% (estimated at 2005 food production levels) in order to meet the food demand in 2050 [1]. A significant part of this growth will take place in developing countries, where steadily increasing urban population continue to create complex and lengthy food supply chains involving many actors, presenting challenges in developing safe, and nutritious food that is of good quality [3]. Post-harvest losses (PHL) are a measurable reduction in foodstuffs, which may affect quantity or quality [4]. For many households, such losses threaten food nutrition, and income security [5]. They also contribute to high food prices by removing part of the food from the supply chain. Food availability and accessibility can be increased by upping production, improving distribution, and reducing the losses. Thus, reduction of post-harvest food losses is a critical component of ensuring future global food security. However, production resources including land, water and energy are limited and inelastic [6].

The Food and Agricultural Organization (FAO) forecasts that about 1.3 billion tonnes of food are globally wasted or lost per year [7]. This is equivalent to thirty percent of food produced for human consumption for the same period. Some reports have estimated that this lost or wasted food could be used to feed 1.6 billion people every year [6].Food losses refer to the decrease in edible food mass throughout the part of the supply chain that specifically leads to edible food for human consumption [7]. They state that food waste or loss is measured only for products that are directed to human consumption, excluding feed and parts of products which are not edible. Reduction in these losses would increase the amount of food available for human consumption and enhance global food and nutrition security, a growing concern with rising food prices due to growing consumer demand, increasing demand for biofuel and other industrial uses and increased weather variability ([8]; [9]). A reduction in food losses also improves food and nutrition security by increasing the real income for all the consumers [10].

The loss of harvested food commodities can be qualitative or quantitative. Quantitative losses are easy to determine and report since they constitute a physical reduction in the marketable volume and can be easily measured. Globally, quantitative grain losses are estimated to be ten to twenty percent of the total volumes [6]. Qualitative losses refer to deterioration of nutritional quality, safety and grade. Qualitative loss data is hardly ever reported. But it is a loss that must concern everyone. For example, the levels of qualitative losses due to aflatoxin contamination, although not reported, have dire long-term effects on health. Chronic dietary exposure to low doses of aflatoxin is a known risk factor for liver cancer and other health-related issues.

Over the past decades, significant forms and resources have been allocated to increase food production. For example, 95% of the research investments during the past 50 years were reported to have focused on increasing productivity and only five percent directed towards reducing losses ([11]; [12]; [13]). Increasing agricultural productivity is critical for ensuring global food and nutrition security, but this may not be sufficient [1]. Food production is currently being challenged by limited land, water and increased, weather variability due to climate change. To sustainably achieve the goals of food and nutrition security, food availability needs to be also increased through reductions in the post-harvest process at farm, retail and consumer levels [1].

Food losses do not merely reduce food available for human consumption but also cause negative externalities to society through costs of waste management, greenhouse gas production and loss of scarce resources used in their production [1]. Food loss is estimated to be equivalent to 6-10% of human-generated greenhouse gas emissions ([7]; [14]). A significant contributor of this problem is through methane gas generation in landfills where food waste decomposes anaerobically [15]. The United States Environmental Protection Agency (USEPA) reports that in the United States of America about 31 million tonnes of food waste accounted for 14% of the 2008 solid waste produced in the country [16] costs roughly US$1.3 billion to landfill ([17];[15]).

A study by the Institute of Mechanical Engineers indicates that current agricultural practice uses 4.9 Gha (global hectares or 4,931million hectares) of the total 14.8 Gha (14,894 million hectares) of land surface on Earth [18]. Agricultural production in addition uses 2.5 trillion m^3 of water per year and over 3% of the total global energy consumption [18]. With estimated food losses of about 30-50% of total production, this translates to wasting 1.47 – 1.96Gha of arable land, 0.75 – 1.25 trillion m^3 of water and 1% to 1.5% of global energy [18].

Given the significant role food loss reductions could have toward sustainably contributing to global food security, it is important to have reliable measures of these losses. Unfortunately, most of the available post-harvest loss and food waste estimates are based on the anecdotal stories with few actual measured or estimated numbers. Moreover, these numbers, in turn, feed into estimates of food availability which are widely used in food and nutrition security assessments and policy analysis.

The history of food waste is closely linked to globalization [19]. In an ever more networked world, supply chains get longer, and everything is available everywhere – Indian mangoes in Germany and American apples in Indonesia – the whole year round. On that often-long journey from farm to table, food is lost or wasted at every stage, and fresh foods such as fruits, vegetables, dairy and meat are particularly vulnerable[19].

Food loss typically refers to food lost in earlier stages of production such as harvest, storage and transportation. Food waste refers to items that are fit for human consumption but thrown away, often at supermarkets or by consumers. Food loss and waste and their ripple effects on the environment, society and economy have become an increasing global concern. With every gram of food produced and then wasted, there are associated wastages in water, energy, capital, nutrition and other related resources.

The total volume of water used to produce food that is lost on an annual basis is equivalent to the yearly flow of the Volga River in Russia which is (8060 cubic metres/second); it is three times the volume of Lake Geneva (89 km3)[19]. In terms of land, 28% of the global arable area (1.4 billion hectares of land) is used to produce food that is lost or wasted annually[19].

Furthermore, food waste has been noted to immensely contribute to climate change through greenhouse gas (GHG) emissions. The carbon footprint of wasted food is approximately 3.3 billion tonnes of carbon dioxide (CO_2) released into the atmosphere on an annual basis.

In Africa, PHL account for up to a fifth of harvests, thereby negating the benefits of investments aimed at ensuring increased productivity towards food and nutrition security[19]. The Inaugural Biennial Review Report (BRR) released by the African

Union Commission in January 2018 shows that the continent is not on track in terms of its efforts towards the Reduction of PHL, having scored zero in 2017, against a target of 10% towards the 2025 target [19]. A key challenge related to this performance on postharvest management (PHM) is the inability of countries to capture and record data on physical losses, perhaps as a result of unavailability or weak national monitoring and evaluation systems as highlighted by the 2017 BRR.

Generally, any loss of produce translates to lost production resources, mainly land, water, energy and inputs. It is also lost income for the various actors in the supply chain. A 2011 World Bank study estimated the value of African grain losses alone stands at USD4 billion. It has been shown that 470 million smallholder farmers suffer a decline of 15% income, while 25% of fresh water and 20% of farmland is wasted in unconsumed food [6].

II. PROBLEM STATEMENT

Global food waste is a far-reaching problem with tremendous financial, ethical and environmental costs. The causes range from ungraded roads to overly-selective customers, but regardless of cause, we can all pitch in to combat this global issue. An estimated 1.3 billion metric tonnes of food is wasted worldwide each year, one third of all food produced for human consumption according to the FAO. In Africa the losses are even higher, between 30% and 50% (with cereal, the main staple food, postharvest losses estimated to be about 15%, [20]).

The amount of food lost or wasted costs US$2.6 trillion annually and is more than enough to feed about 815 million hungry people in the world four times over. The world food production must increase by sixty percent come year 2050 in order to meet the demands of the growing world population. Yet, more than one third of the food produced today is lost or wasted.

III. METHODOLOGY

This paper reviews the Post-harvest problems/issues. Mainly the consequences of PHL, on the African continent. It is a research review article which is qualitative (some quantitative methods will be used) in its approach; mainly concerned with and verifiable by both experience and observation rather than theory or pure logic. The qualitative method used here is mainly meant to gather data and find meanings, strategies, opinions, experiences related to PHL in Africa and other developing continents, for example, Asia and South America. Comparisons are made with the developed countries.

In order to comprehend on what is currently known about PHL, literature will be drawn from journals, working papers, unpublished theses, publications from government, the likes of FAO, World Bank, Non-Governmental Organisations and global agribusiness industry.

The sequence of this review is to study definitions of PHL; causes of PHL; examples of types of food losses/waste; drivers of food losses; PHL critical points; extent of food losses and waste; energy and food losses; the economic consequences of PHL; indications of results/findings; post-harvest technology objectives; PHL management strategies; and conclusion and recommendations.

IV. LITERATURE REVIEW

4.1 Defining Post Harvest Losses:

It is essential that common ground be established as issues of PHL, food waste, food and nutrition security and other similar terms have oftentimes been confused with each other or are given different meanings within the concept of PHL management. The expression “PHL” means a measurable quantitative and qualitative loss in a given product. These losses can occur during any of the various phases of the post-harvest system. This definition must also consider cases of product deterioration.

Food losses are defined *“as the decrease in edible food mass throughout the part of the supply chain that specifically leads to edible food for human consumption”*([21], p3). Food losses take place at the production, harvesting, primary handling, aggregation, storage, transport, processing, distribution and consumption segments [22]. Food losses occurring on the demand side of the food chain (retail and final consumption) are generally referred to as “food waste”, which relates to retailers’ and consumers’ behavior [23] as quoted by ([21], p3). In [22] Definitional Framework of Food Loss working paper, ‘food loss’ is simply defined as the decrease in quantity or quality of food.

The following was a summary of PHL by [24; 25]:

- Measurable quantitative (volume) and qualitative (nutritional and monetary value) loss in a given agricultural product.
- Occurrence in during various stages of the post-harvest system.
- The physical characteristics considered are shape and size of the produce, moisture content, impurities such as pebbles, soil and plant residues, fragments of glass or metal, animal hairs, excrement, degree of infestation by insects or micro-organisms.
- Rather than actual losses, it would be more accurate to call it restriction in the use of the product.

Consequently, post-harvest is not only multidimensional but multidisciplinary involving the agriculture sector, agri-processing industry, health and nutrition sector, distribution and manufacturing sectors, among others.

Thus, food waste is the loss of edible food due to human action or inaction such as throwing away wilted produce, not consuming available food before its expiry date, or taking serving amounts beyond one's ability to consume [22]. Food waste is strongly linked with the consumer's behavior, that is, consumer's refusal to purchase the food and/or discarding of leftover food[25]. The Definition Framework of Food Loss working paper, "quantitative food loss" is simply defined as the decrease in mass of food [22]. The quantity lost would have either deteriorated rendering it inedible or discarded for failure to meet regulated standards to eat as a food or to use as an animal feed.

The Post-harvest food loss can also be defined as the loss from the stage of harvesting to the stage of consumption which occurs as a result of qualitative loss quantitative loss and the food wastage (by the consumers).

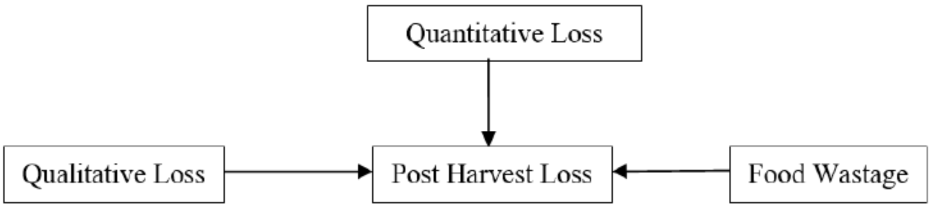

FIGURE 1: Post-harvest food loss components.
Source:27

While, qualitative food loss is when food loses its quality attributes resulting in the deterioration in quality leading to a loss of economic, social and nutritional value[26]. The qualitative loss can occur due to incidence of insect pest, mites, rodents, and birds, or from handling, physical changes or chemical changes in carbohydrates and protein, and by contamination of mycotoxins, pesticide residues, insect fragments, or excreta of rodents and birds and their dead bodies[27]. When this qualitative deterioration makes food unfit for human consumption and is rejected, this contributes to food loss [26].

Post-harvest loss can also be defined as the degradation in both quantity and quality of a food production from harvest to consumption [28]. Quantity losses include those that afford the nutrient/calorific composition, the acceptability, and the edibility of a given product [28]. These losses are generally more common in developed countries [27]. Quantity losses refer to those that result in the loss of the amount of a product [28]. Loss of quantity is more common in developing countries [29].

Therefore, food that was originally meant for human consumption but which fortuity gets out the human food chain is considered as food loss or waste even if it is then directed to a non-food use (feed and bioenergy) [7].

4.2 Causes of Post-Harvest Losses:

In industrialised countries food gets lost when production exceeds demand. In order to ensure delivery of agreed quantities while anticipating unpredictable bad weather or pest attacks, farmers sometimes make production plans on the safe side and end-up producing larger quantities than needed, even if conditions are average. In the case of having produced more than required, some surplus crops are sold to processors of animal feed. To prevent this, [30], suggests that there must be communication and cooperation between and among farmers so that they can reduce risk of overproduction by allowing surplus crops from one farm/region to solve a shortage of crops or any other.

There are generally three main causes of PHL, namely [30]:

- Disease caused by fungi and/or bacteria
- Physical injuries due to insects, mechanical force, chemicals, heat, rain or freezing

- Non-disease disorders resulting from storage conditions that upset normal metabolism when the product is rejected further down the marketing chain.

Post-harvest losses can be categorized into five types:

1) Biological: Pest and disease
2) Chemical: Visible external contamination with pesticides and chemical products, toxics and unpleasant flavor produced by pathogens.
3) Mechanical: Injuries, cuts bruises, grazes, drops, scrapings, shatters during harvesting, packing and transporting.
4) Physical: Heating, cooling, freezing, water loss.
5) Physiological: Sprouting, rooting, senescence and changes caused by transpiration and respiration.

TABLE 1
CAUSES OF TOTAL FOOD LOSS DURING THE POST-HARVESTING CHAIN: SOURCE [31]

Harvesting	Food Storage	Processing	Packaging	Marketing	Consumption
1) Poor production practices 2) Climatic conditions	1) Attack by insect, moulds, rodents, 2) Deterioration 3) Shrinkage 4) Spoilage 5) Humidity 6) mproper handling 7) Temperature	1) Removal of damaged portions. 2) Discarding of substandard product 3) Visual based rejection 4) Package failures 5) Shrinkage	1) Packaging failures 2) Transportation losses 3) Lack of packaging services	1) Improper portioning 2) Supersizing 3) Poor inventory 4) Dented cans	1) Left-overs 2) Impulse buying 3) Infrequent market visits 4) Poor portioning 5) 5. Bulk purchase

Internal and external factors contributing to PHL[28]:

A. Internal Factors:

- *Harvesting.* Time of harvesting is determined by degree of crop maturity and weather conditions. Primary causes of losses at the harvest stage include (1) absence of an established maturity index for some commodities, and/or lack of maturity index for local export markets, (2) low adoption of established indices, as price and distance to market influence adoption and (3) poor weather at harvest time which affects the operations and functionality of harvesting machines or human labour and usually increases the moisture content of the harvested products.

- *Pre-cooling*. Loss at this stage is primarily due to the high cost and lack of availability of pre-cooling facilities, inadequate training on pre-cooling technology at the commercial scale and lack of information on cost benefits of pre-cooling technology.

- *Transportation.* Primary challenges in the transportation stage of the supply chain include poor infrastructure (roads, bridges, communication), and a lack of refrigerated transport. In most developing countries, roads are not adequate for proper transport of horticultural crops. Transport vehicles and other modes of transport, especially those suitable for perishable crops are not widely available. Small-scale producers in Africa have smallholdings and cannot afford to purchase transport vehicles. In a few cases, contract farming arrangements, marketing organisations and cooperatives have been able to provide and acquire transport vehicles but cannot alleviate poor road conditions [27].

- *Storage* (granaries, warehouse, hermetic bins, silos). Facilities, hygiene, and monitoring must all be adequate for effective, long-term storage. Control of cleanliness, temperature and humidity is particularly important. It is also very important to manage pests and diseases can lead to deterioration of facilities and result in losses in quality and food value as well as quantity.

- *Grading.* Proper packing and packaging technologies are critical in order to minimize mechanical injury during the transit of produce from rural to urban areas. Causes of PHL in the grading stages are (a) lack of national standards and poor enforcement of standards (b) lack of skill (c) awareness and (d) financial resources.

- *Packaging and labelling.* After harvest, fresh fruits and vegetables are generally transported from the farm to either a packing house or distribution centre. Farmers sell their produce in fresh markets or in wholesale markets. At the retail level, fresh produce is tied in bundles. This type of market handling of fresh produce greatly reduces its shelf life if it is not sold quickly.

- *Biological.* Biological causes of deterioration include respiration rate, ethylene production and action, rates of compositional changes (associated with colour, texture, flavour and nutritive value), mechanical injuries, water stress, sprouting and rooting, physiological disorders and pathological breakdowns. The rate of biological deterioration depends on several environmental factors, including temperature, relative humidity, air velocity and atmospheric composition (concentration of oxygen, carbon dioxide and ethylene) and sanitation procedures ([32]; [27]; [33]).

- *Microbiological.* Micro-organisms cause damage to stored foods (for example, fungi and bacteria). Usually, micro-organisms affect directly small amount of the food but they damage the food to the point that it becomes unacceptable. Toxic substances elaborated by molds (known as mycotoxins) cause loss in food quality and nutritional value.

- *Chemical.* Many of the chemical constituents naturally present in stored foods spontaneously react causing losses of colour, flavours, texture and nutritional value.One such reaction is the mallard reaction that causes browning and discolouration in dried fruits and other product. There can also be harmful chemicals such as pesticides or obnoxious chemicals such as lubricating oil [34].

B. External Factors:

Factors outside of the food supply chain can cause significant PHL. These factors can be grouped into two primary categories, that is, environmental factors and socio-economic patterns and trends.

Environmental factors. Climatic conditions, including wind, humidity, rainfall, and temperature influence both the quantity and quality of a harvest [4]:

- *Temperature*. The higher the temperature the shorter the storage life of horticultural products and the greater the amount of loss within a given time[34].

- *Humidity*. There is movement of water vapour between stored food and its surrounding atmosphere until equilibrium of water activity in the food and atmosphere is reached. A moist food will give up moisture to the air while a dry food will absorb moisture from the air. Fresh horticultural products have high moisture content and need to be stored under conditions of high relative moisture loss and wilting (except for onions and garlic). Dried or dehydrated products need to be stored under conditions of low relative humidity in order to avoid absorbing moisture to the point where mould growth occurs [34].

- *Altitude.* Within a given latitude the prevailing temperature is dependent upon the elevation when other factors are equal. There is on the average a drop in temperature of 6.5^{0}C [34], for each kilometer increase in elevation above sea level. Storing food at high altitudes will therefore tend to increase the storage life and decrease the losses in food provided it is kept out of direct rays of the sun [35].

- *Time.* The longer the time the food is stored the greater is the deterioration in quality and the greater is the chance of damage and loss. Hence, storage time is a critical factor in loss of foods especially for those that have a short natural shelf life.

Some produce is rejected by supermarkets at the farm gate due to rigorous quality standards concerning weight/mass, size, shape and appearance of crops [7]. This results in large portions of crops not leaving the farms. Even though some rejected crops are used as livestock feed, the quality standards might divert food originally aimed for human consumption to other uses [30]. Supermarkets seem convinced that consumers will not buy food which has the ‘wrong’ weight/mass, size or appearance.

However, surveys done show that consumers are willing to buy heterogeneous produce as long as the taste is not affected [30]. Consumers have the power to influence the quality standards. This could be done by questioning them and offering them a broader quality range of products in the retail stores [23]. Selling farm crops closer to consumers without having to pass the strict quality standards set up by supermarkets on mass, size and appearance would possibly reduce the amount of rejected crops [36]. This can be achieved through, for example, farmers markets and farm shops [30].

Poor storage facilities and lack of infrastructure cause post-harvest food losses in developing nations. Fresh products like fruits, vegetables, milk, meat and fish straight from the farm or after the catch can be spoilt in hot climates due to lack of infrastructure for transportation, storage cooling and markets ([36]; [30]). To prevent this governments should improve the infrastructure for roads, energy and markets. Subsequently, private sector investments can improve storage and cold chain facilities as well as transportation [37].

Failure to comply with minimum food safety standards can lead to food losses and in extreme cases, impact on the food security status of a country[36]. A range of factors can lead to food being unsafe, such as naturally occurring toxins in food itself, contaminated water, unsafe use of pesticides and veterinary drug residues[7]. Poor and unhygienic handling and storage conditions and lack of adequate temperature control can also cause unsafe food[36]. Food chain operators should be skilled and knowledgeable in how to produce safe food. Foods need to be produced, handled and stored in accordance with set food safety standards. This requires the application of good agricultural and good hygienic practices by all food chain operators to ensure that the final food protects the consumer[30].

The attitude of disposing off food products is cheaper than using or re-using in industrialised countries leads to a lot of food waste[37]. This occurs on the food processing lines when carrying out trimming to ensure that the end product comes out in the right shape and size[37]. The trimmings in some cases, could be used for human consumption but are usually disposed of. Food might be lost during processing because of spoilage down the production line. Sometimes errors on the processing line lead to end-products with the incorrect mass, shape or appearance, or damaged packaging, without affecting the safety, taste or nutritional value of the food[37]. In a standardized production line these products often end up being discarded ([30]; [38]).

4.2.1 Types of Post-harvest Losses:

Direct and Indirect Loss: Direct loss is food lost through spillage of crops from bags and consumption by pests. Indirect loss is food waste which occurs at the consumer level, that is, left overs, refusal to purchase.

Weight Loss: The observable loss which can be measured by reduction in moisture content. Prolonged storage, shrinkage, pests, poor packaging, leakages.

Food Loss: Occurs as a result of loss qualitatively and quantitatively.

Qualitative Loss: Deterioration of quality via degradation of nutrients, texture, taste shape, for example, carbohydrates, proteins, vitamins act as food for:

- Weevils – feed inside seed crops where high carbohydrates are located
- Some insects attack the cereal cover rich in vitamins
- Moulds and bacteria attack on high perishable foods (fruits and vegetables) because they have a high moisture content which is fed upon
- Loss due to the excreta of birds and animals, pesticides, pathogenic organisms

Quantitative Food Loss: reduction in weight through heat (moisture loss), rodents, birds, animal, leakages during transportation. Rice, maize, wheat are typical examples.

Seed Viability Loss: reduced viability lowers yields (temperature, moisture, sun)

Commercial Loss: Value of produce goes down because of customer low demand, rejection by down grading. Qualitative and Quantitative losses.

Irreducible Loss: excessive respiration of the product, mechanical rubbing of the grains, shrinkage in the produce, mechanical injuries. To compensate for this, more has to be produced than required.

4.2.2 Main Drivers of Food Losses as observed by [39]:

In developing countries food is lost due to infrastructural constraints including lack of access to modern energy to drive improved food processing technologies and to optimize storing facilities.

- One of the main causes of food losses is biological spoilage due to lack of appropriate storing infrastructure.
- Livestock products, fish, fruits and vegetables lose value very quickly without refrigeration. A large proportion of fresh products such as fruits, vegetables, meat and fish, straight from the catch or the farm are spoiled due to lack of cooling, drying and technologies that would enable safe storage. They lose quantitative and qualitative value if stored in an unregulated environment with high temperatures. They also lose value due to mechanical damage during harvesting and handling and improper post-harvest sanitation.
- Roots and tubers are less susceptible than fruits and vegetable to biological decay but post-harvest storage and processing are required to limit losses. Especially with potatoes for example which require a high humidity environment to prevent sprouting. They are normally stored at a temperature of 4 to 7^{o} C and relative humidity of 90% in a dark location, as potatoes turn green when exposed to light. If storage temperatures are above $7^{0\ C,}$ the potatoes will startto sprout after two or three months.
- Cereals are the least susceptible to PHL but may be scattered, dispersed and crushed during handling. In developing countries, cereals are often dried directly under the sun on open ground due to lack of appropriate drying technology resulting in losses due to pest and rodent attacks. Losses are even higher under unfavourable weather conditions when open sun drying is not possible. (Suboptimal drying practices and poor storage of grain can lead to the growth of micro-toxin producing moulds which produces aflatoxin, a potent carcinogen [40]).

A typical food value chain along with the reasons of food loss and waste at each stage:

TABLE 2
FOOD VALUE CHAIN AND REASONS FOR FWL

Production	Handling & Storage	Processing & packaging	Distribution & marketing	Consumption
Food loss while harvesting	Food lost on farm or off-farm and storage	Food lost during processing at village level or industrial	Food lost during transportation to wholesale or retail markets	Food lost at home or business, including in restaurants
Damage while harvesting	Biological degradation due to poor storage	Edible food sorted out as not fit for processing	Food sorted out due to quality	Purchased food not eaten
Sorting out of crops due to not meeting quality and aesthetics standards	Pest and rodent attacks	Losses during processing like canning and packaging	Food reaching expiry date before being purchased	Food wasted due to large portions
Crops not collected due to poor harvesting or lack in demand	Often caused by inadequate access to modern energy	Often caused by inadequate access to modern energy	Food does not look aesthetically fit although is edible	Food reaching expiry date before being cooked

Source: Adapted from [41]

4.2.3 Critical Post-harvest Loss Points:

It has been established from research and assessment results over the years such that it is now common cause that PHL occur throughout the agricultural chain. Obviously, the quantum differs by stage and by level of sophistication and efforts designed to reduce PHL. The figure (2) below shows where PHL occur in the chain:

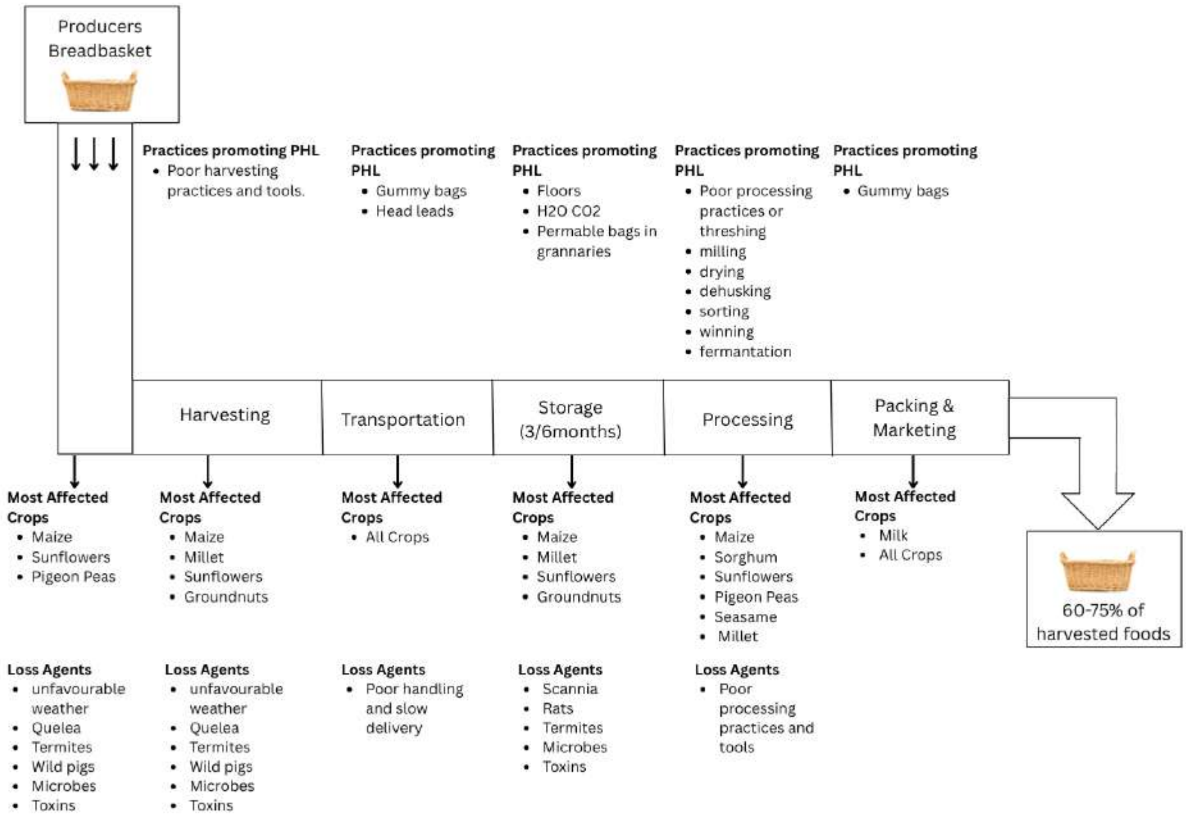

FIGURE 2: Post -harvest throughout the Agricultural Value Chain

Source 42: Presentation by FANRPAN during AU-FAO Post-harvest Regional Workshop, Nairobi, Kenya 24, 25 July 2018

In this review, food and nutrition security is mentioned quite often and therefor it is necessary to describe it. Food and nutrition security is anchored on Four Pillars of (1) Food Availability, (2) Access to Food, (3) Utilisation of Food, (4) Stability of supply of food must exist. See figure 3 below:

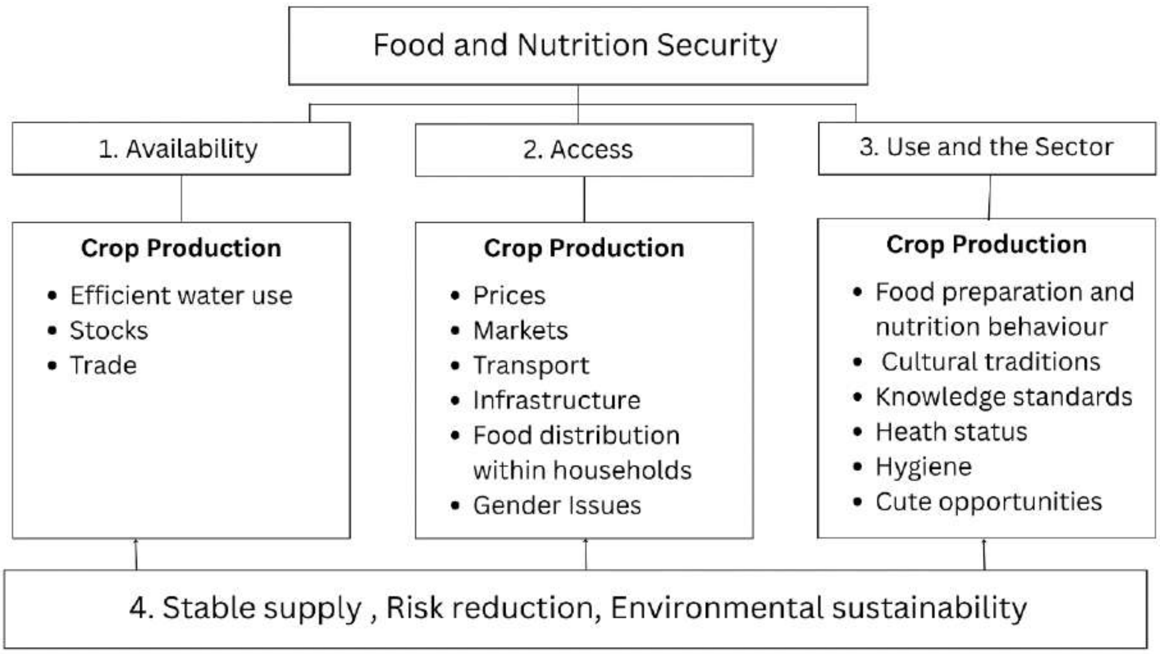

FIGURE 3: The four Pillars of Food and Nutrition Security

Source 43: Adapted from - FAO

Also, as defined PHL occur both in quantitative terms, affecting the food availability pillar of food and nutrition security, and in qualitative terms affecting the food use and utilization pillar as well as the food availability pillars of the food and nutrition security. Apart from reducing the total amount and quality of food available, PHL also exacerbate the already fragile poverty ridden rural economies by eroding income generation along the food value chain and therefore affect the accessibility as well as sustainability pillars of food and nutrition security [43].

4.2.4 Extent of Food Losses and Waste:

The per capita food loss in Europe and North America is 280-300 kilograms per year, in Africa and South/Southeast Asia it is 120-170 kilograms per year [7]. While the per capita production of edible parts of food for human consumption is in Europe and North America about 900 kilograms per year and in Africa and South/Southeast Asia 460 kilograms per year [7]. Per capita food wasted by consumers in Europe and North America is 95-115 kilograms per year and in Africa and South/Southeast Asia is only six to eleven kilograms per year [7].

Food losses in industrialised countries are as high as in developing countries, but in developing countries more than 40% of the food losses occur at post-harvest and processing levels, while in industrialised countries, more than 40% of the food losses occur in retail and consumer levels. Food waste at consumer level in industrialised countries (222 million tonnes) is almost as high as the total net food production in Africa (230 million tonnes).

Reducing PHL is a key pathway to food and nutrition security in Africa. However, knowledge of PHL magnitudes is limited. In 2014 [42] conducted a meta-analysis to expose the nature and magnitude of PHL, and the kinds of interventions that have been attempted to mitigate the losses. Their findings reveal inadequacies of loss assessment methodologies that result in inaccurate PHL estimates [42]. Moreover, losses are often economic rather than physical product losses. Overall, technologies for loss mitigation fail to address dynamics of supply chains. Consequently, rigorous PHL assessment using systematic methodologies, as well as holistic approaches for losses mitigation are in need.

4.3 Energy and Food Losses:

([39]; [45]; [46]; [47] IoMe, 2014; [48]) listed the following as important facts to be considered when discussing PHL:

- Approximately one out of every four calories grown to feed people is not ultimately consumed by humans.
- Food Loss Wastage (FLW) of 1.3 billion tonnes of food results in (a) loss of almost 1.4 billion hectares of land that were used to produce that was not consumed, (b) a global blue water footprint for the agricultural production of food wastage was about 250km^3 in 2007; 3.6 times the blue water footprint of total United States of America consumption, (c) GHG emissions of an estimated at 4.4 giga-tonnes of CO_2 equivalent translating to approximately eight per cent of anthropogenic emissions (if food loss was a country, it would be the third largest emitter after China and the USA), (d) an estimated 38% of total energy consumed by food systems is utilised to produce food that is ultimately never consumed by humans.
- The cold chain is the key to tackling the loss of perishable produce. It is estimated that around a quarter of the total food wastage in developing countries could be eliminated if these countries adopted the same level of refrigeration equipment as that in developed economies.
- The challenge is that in nearly all cases, cooling and refrigeration rely on access to a reliable and affordable source of either electricity or diesel fuel, which are often lacking or virtually non-existent in developing countries, particularly in rural areas where energy security is a significant issue.
- If fifty percent of the food waste generated each year in the USA was anaerobically digested, enough electricity would be generated to power over 2.5 million homes for a year.

Currently, agriculture already uses around eleven percent of the world’s land surface for crop production, and accounts for 70% of all water withdrawn from aquifers, rivers and lakes[48]. Additionally, the food system currently accounts for about 30% of the world’s total energy consumption and is responsible for about 20% of the GHG emissions [46].

The main drivers of FLW can broadly be divided into two main categories, that is, behavioural and infrastructural [49]. Human behaviour and preferences towards foods having specific aesthetic requirement may lead to food, which is fit for human consumption being wasted[49]. A large proportion of food is wasted in industrialised countries due to the prevalence of strict grading and aesthetic standards and waste due to consumer behaviour [50]. Infrastructural limitation on the other hand lead to food being lost due the non-existent or inefficient infrastructure such as food harvesting, storing and processing technologies but also roads for transportation of food along the value chain[49]. A key component of infrastructural limitation is the post-harvest technologies which include modern or traditional harvesting, processing and storing technologies which facilitate the maintenance of quality (appearance, texture, flavour and nutritive value), the protection of food safety and the reduction of losses (both physical and in market value) between harvest and consumption[50].

4.4 The Economic Consequences of PHL:

The annual value of postharvest cereal grain loss in Africa is estimated to be up to US$4 billion of an annual production of US$27 billion [20]. This figure exceeds the total value of food aid that the continent has received over the past ten years (it equals roughly to the annual value of cereal imports into the continent; it is enough to satisfy annual caloric requirements for at least 48 million people). Yet a one per cent reduction in PHL can be translated into US$40 million annual gains for Africa [20].

The world's increasing population and demand for food, reducing food loss and waste is one of the greatest challenges worldwide [51]. Current estimates point to over one billion tonnes of food is lost and wasted worldwide, though nearly ten percent of the global population is suffering from undernourishment and food insecurity. In Mozambique, for example, about one-quarter of the population suffers from undernourishment and food insecurity [52]. Estimates from FAO point to PHL of maize in Mozambique at about 3.69 to 7.92%, this is less than one fifth of on-farm losses reported by other authors or researchers.

Food production relies on an ecological resource base that is coming under increased pressure and has to support multiple demands [53]. Land area is needed for food production, animal feed, timber and other purposes, often at the expense of natural forest lands. Likewise, aquatic ecosystems and fish stocks have to support a growing fisheries industry, which includes fish feed for aquaculture [54]. The land use sector has to be more productive by making more efficient use of the resources available. Current estimates indicate that approximately 28% of the world's agricultural land area is occupied to produce food that is never consumed by humans [52]. Food loss and waste, through the inefficient and unsustainable handling of food, has impacts on deforestation, ecosystem degradation and natural resource depletion. In addition, each year approximately 35% of global fish and sea food products are either lost or wasted, with a considerable proportion due to discards at catch level [21]. This number is unacceptably high considering that fish stocks and their supporting ecosystems are overexploited and degraded worldwide due to poor governance, management and fishing practices [55].

The natural resources and inputs needed in the process and the actions related to waste disposal all generate GHG emissions that contribute to climate change. These aggregated impacts make food loss and waste a major contributor to climate change, accounting for about eight per cent of total global GHS emissions [56], while undermining both human and ecological capacities to cope with climate change.

Irrespective of the country development status, in terms of volume, most food is lost at the agricultural production stage of the supply chains, although for varying reasons [57]. In industrialised countries, field losses at the production stage reflect economic decisions of the farmer to forgo harvesting due to market conditions or due to non-conformity of the produced food to the grading and aesthetic standards set by the consumers[39]. In developing countries however, field losses at production stage result from poor state of the value chains and infrastructure [39]. Specifically, due to the combination of poor education, farming methods (including improper handling, inefficient harvesting methods and premature harvesting) and infrastructure[49]. Pests, disease, overplanting (often motivated by the uncertainty of the weather) and labour shortages contribute to losses at this stage.

On a per capita basis, more food is wasted in industrialised countries than in developing countries, peaking at 280-300 kilograms per capita per year in Europe and North America and around 120-170 kilogram per capita per year in Africa and

South/Southeast Asia [49]. While fruits and vegetables being highly perishable constitute the largest share of the total food lost by mass, PHL in cereals comprise the largest share by calorific content [39]. In SSA specifically, around 36% of food harvested is lost equating to an average 167 kilogram per capita per year where only seven kilograms are at the consumer level [57].

According to [58], food and nutrition security means, when all people at all times, have physical, social and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for active and healthy life. The majority of studies on PHL have concentrated on looking at the sustainability of food systems as regards to human food and nutrition security and natural resource management ([52]; [59]; [54]; [41]; [60]. Unfortunately, there has not been much research work (systematic and empirical) on the impact of PHL on food prices to inform the global policy and regulatory debate [61]. This encouraged [61] to do research on this in order to bridge this information gap and provide policy-makers and practitioners with insights on potential impacts of food loss and waste reduction on prices at inter- and intra-regional level.

The results showed that reducing PHL can be beneficial in reducing overall food prices, which has differential impacts across producers and consumers in the Western Europe and Africa, for example[61]. In general, Africa experiences welfare losses but these areas are small fraction of the economy. This outcome was the result of different, that is, positive and negative impacts on various actors in the African economies, including impacts on producers as sellers losing out from increased competition from EU food producers [61]. The effects are highest in regions where action is being taken to reduce food loss and waste, that is, the EU thus providing a compelling argument for policy-makers waiting to tackle high food prices to enact plans/actions in their respective regions and/or countries to reduce PHL[54].

The complex interactions between supply and demand shifts arising from PHL reduction illustrate that it is difficult to predict the potential socio-economic impacts of such actions, especially in a world that is continuously and rapidly changing and that trade-offs are likely to occur[61].This provides useful insights into what might happen and provides a useful starting point for further and more complex foresight analysis of what the world may look like now and beyond [61].Work is required in the following areas:

- Food loss and waste should be incorporated explicitly in the modelling of the food system, preferably as endogenous outcomes or activities that have returns and costs, so that underlying causes and measures to tackle food loss and waste, and associated costs can be modelled.
- Short-term impacts maybe analysed by adjusting the model for market rigidities/imperfections that result in more vehement price changes.
- If interested in distributional impacts, the model needs to be adapted to include different types of households to account for differential welfare impacts across net food consumers and net food producers.

A major obstacle in the efforts to achieve PHL mitigation is the lack of clear knowledge of the real magnitudes of losses, which makes it impossible to measure progress against anyloss reduction targets [62]; [63]. Uncertain estimates of PHL, coupled with imprecise understanding of the points in value chains where the losses occur as well as the socio-economic factors for the losses could end in policy errors and sub-optimal choices of mitigation approaches [62]. In the literature, estimates of PHL magnitudes vary widely. Figures between 10-40%, and as high as 50-70% are regularly quoted ([64]; [65]; [66]; [66; [23];[68], often from untraceable sources. Furthermore, many estimates link to datasets collected thirty years ago, and are fragmentary and unconsolidated. Whereas the FAO-World Bank "Missing Food" report [5] made a significant contribution in demonstrating current knowledge on the nature, magnitude, and economic value of PHL for stored grains in Africa, a lot more information is still lacking especially concerning commodities other than cereal grains that are equally important for nutrition and for security. Moreover, the report and several other studies ([64]; [7]; [23]; [68]) also point out that major data gaps do exist on the quantification of PHL in Africa.

4.5 Discussions and Implications of Results/Findings:

4.5.1 Evidence of PHL:

In their meta-analysis, [62], found out that evidence of PHL in Africa is sketchy, and quantitative estimates are often derived from inadequate datasets. It is pragmatic for research to focus on losses at a particular level of the value chain where the loss is considered to be significant and potentially recoverable [62]

The major reason for many unreliable PHL estimates is weak assessment methodologies[64]. Many datasets do not account for the interaction of various loss agents and are single-point measurements which omit influence of exogenous factors such as local food use patterns, practices and coping strategies [62]. The omission of social, cultural, economic and ecological factors in loss assessment could lead to over or under estimation of actual losses [69]; [70]; [5]. Such factors could include level of wealth and vulnerability, awareness and technology exposure, perceptions and attitudes, destination of products, farming systems, agro-climatic conditions and pest prevalence [63]. Variability in accuracy and practical application of different losses assessment methods, also exist depending on the nature of the commodity and the type of loss agents [71]; [72]; [73]; [74]). For some commodities such as fresh produce and fish, there are no reliable methods of evaluating PHL as most methods are often subjective ([75]; [76]).

4.5.2 On-farm storage versus value chain:

Most efforts to assess PHL have targeted smallholder farm-level activities, particularly storage, whereby insect infestations and biological deteriorations are the two factors that strongly attract attention [62]. A reason for the skewed focus toward storage losses is because harvested produce is stored for considerable periods so as to counter erratic production patterns, to speculate on price and to guarantee smooth income tenures [77]. The scope has, however, been limited considering that contributions of other food loss agents including rodents, molds, spillage and pilferage remain untracked [62].

Food consumption trends in developing countries including Africa are undergoing transitions [62]. Rapid urbanization and changes in social and cultural practices have modified food habits of communities [78].Thus, unlike in the past, strategies for managing PHL can no longer concentrate on farm-level activities, ignoring the rest of the post-production chain where value addition also takes place [62]. Sorting and grading losses, for instance, are often very important, especially in markets that thrive in quality. Products that are regarded unfit at one market level could be channeled to lower-end markets or be diverted to alternative uses thereby minimizing the overall economic impact of losses [62]. Some alternative uses like bio-energy generation and animal feed processing can generate employment and incomes or directly support the main PHL reduction investment [63].

4.5.3 Economic, quantity and quality losses:

As part of PHL, quality losses impact on food safety, nutritional value and often economic value as successful markets depend on a consistent supply of good quality produce ([79]; [76]). An overlap between quantity and quality losses exists although many PHL assessments in the past targeted quantity alone [62]. Extremely high-quality losses could translate to 100% quantity loss when entire lots have to be discarded as in the cases of severely insect damaged or aflatoxin-contaminated grains ([80]; [16]). Similarly, in fresh produce, weight loss is physiologically linked to bio-deterioration and therefore loss of quality [79].

A reason why estimation of quality losses is not frequent is complication arising from product seasonally and the extent to which markets are sensitive to quality [62]. For example, when there is low supply of grain, such as during droughts or the periods just before a new harvest, there is hardly any good quality grain on the market so that poor quality grain may sell for a price that is greater than that received for better quality grain during abundant harvest [16]. In many African countries quality standards are not enforced or do not exist and so quality changes may be assessed differently by individual consumers [62]. Findings of the present analysis, nonetheless, indicate that consumers have increasingly become quality conscious ([81]; [82]; [83]) which should raise the perspectives for greater emphasis of quality losses in future PHL research.

4.6 Objectives of Post-harvest Technology:

4.6.1 Some objectives of post-harvest technology [84]:

- Maintenance of food quality, that is, appearance, texture, weight, flavor, nutritive value
- Production of food safety

- Reduction in food losses – between the period of harvesting and consumption by improving harvesting, storage, transportation facilities and marketing policies
- Reduction of food waste – reduce food wastage at consumer level – improving marketing skills, efficient distribution of product. Efficient use of food in household
- Effective management of PHL
- Promotion

4.6.2 Factors affecting Post-harvest Losses:

Primary and secondary factors which affect PHL of food products[85].

Primary factors:

- Mechanical loss: caused by poor handling of produce from harvesting to storage
- Microbial action: caused by micro-organisms like bacteria, fungi, yeasts – fruits and vegetables
- Environmental factors: temperature and relative humidity are two important environmental factors responsible for PHL; (included are physical damage, pathogens, atmospheric composition, light, gravity, rodents and other animals, birds, contamination.

Secondary factors:

- Inadequate harvesting methods
- Incomplete drying before threshing
- Inadequate storage facilities
- Longer shipment
- Lack on market access and policies

4.6.3 Control of Post-harvest Losses [86]:

- Post-harvest loss in fruits and vegetables can be minimized by proper cultural operations, harvesting, transportation, storage and pre and post-harvest treatments
- Interrupted supply of water, for example,causes cracking of carrots, radish, tomato and splitting of outerscales of onions
- Sudden and heavy irrigation at late maturity, results in cracking of water-melons and tomatoes
- Heavy application of nitrogenous fertilisers causes faster tissue deterioration in fruits and vegetables, while essential supply of potassic fertilisers improves the keeping quality of fruits and vegetables.

4.7 Post-harvest Loss Management Strategies:

Reducing food loss and waste presents a key opportunity to improve environmental sustainability and is necessary for achieving inclusive and sustainable food systems [54]. This is emphasized in the 2030 Agenda for Sustainable Development, which sets a global target for food loss and waste reduction. Ensuring that food is handled and consumed more sustainably now and, in the future, requires ambitious and collective global efforts, and transformational change is needed at both the international and individual level [52].

Among the many targets that the African Union Commission was mandated to report on in the Agricultural Review Process is the target to halve the current levels of PHL by the year 2025 under the Malabo Declaration Commitment to ending hunger in Africa by 2025 [43]. In line with this target and with the support from the FAO, the Department of Rural Economy and Agriculture (DREA) of the African Union Commission undertook to support efforts on the continent by developing this, the African Union PHL Management Strategy (PHLMS).

Preventing PHL presents a transformative opportunity to address major drivers of global environmental degradation and loss of biodiversity, while simultaneously helping to achieve food and nutrition security[87].It is unacceptable that natural resources are being depleted and vital ecosystems are degraded to produce food, that is, ultimately never consumed, while seven hundred and ninety-five (795) million people are living in chronic hunger [87].

Developing efficient solutions to reduce PHL and waste lies in the recognition of interlinkages among different stages of the supply chain. In other words, the performance of each actor and cost of activities in upstream segments of the chain could determine the quality of the product further down the food supply chain [3]. For instance, improving on-farm storage facilities to reduce PHL should be coupled with proper strategies and interventions to enhance access to markets [52]. In low-income countries solutions should first and foremost take a producer’s perspective, for example, by improving harvest techniques, farmer education, storage facilities and cooling chains[3]. In industrialised nations on the other hand, solutions at the producer and industrial levels would only be marginal [51], if consumer education and appropriate stock management at retail level is not in place. Moreover, government investment on capacity building for agriculture and infrastructure and policy support to facilitate market access for farmers and to provide an enabling environment for private sector investment is a non-negotiable factor that cuts across most measures to reduce PHL [52].

In Australia (1996-99) a study showed that around 37 000 tonnes of bananas were lost every year due to rejection at the pack house because of not meeting customer specifications for sale as fresh fruit [88]. Banana growers started to work with packaging companies, state primary industry departments and retailers to identify the major causes of fruit damage in the supply chain and provide solutions [3]. It was found out that losses occurred due to fruit damage during transportation, storage and handling and in supermarkets due to poor staff handling (inadequate training) and consumer handling (lack of awareness) [52]. As a result of extensive collaboration and coordination, the supply chain became more streamlined [52]. Research led by a major Australian retailer led to the introduction of cluster packing, the development of the six-per-layer carton, absorbent paper for sap control as well as the development of product specifications and systematic quality assurance to monitor fruit outturn at points along the chain and implementation of improved cold chain and processes from harvest through to retail [89].

Through their research [89] concluded that packaging can play an important role by reducing damage in transit and handling or by extending shelf life.

The implementation of these initiatives could be supported through further research and communication activities to highlight the critical links and trade-offs between packaging consumption, protection and containment of food and food waste.

The key challenges facing Africa as regards PHL, include the lack of [43]:

- Awareness and communication on the impact or consequences of PHL
- Awareness of standardized PHL measurement methodologies
- Targeted policies and/or strategies at the national levels on PHL
- Appreciation of the economic value of PHL and its impact on food and nutrition security
- Research and development including lack of evidence-based PHL assessments
- Institutional and organizational arrangements including lack of support for generation and dissemination of PHL best practices and knowledge

- Targeted financing and investment in PHL activities

Based on available information, Table 3 below shows a summary of the status of PHL strategies of five selected African countries [43]:

TABLE 3
SUMMARY OF THE STATUS OF PHL STRATEGIES OF FIVE SELECTED AFRICAN COUNTRIES

Country	Title of the Document	Rationale for PHL management strategy
Ethiopia	Post-harvest loss management strategy in grains in Ethiopia – October 2016	The strategy was developed on the recognition that focus on primary production had tended to overlook and effectively neglect the importance of PHL with available data suggesting annual losses in the vicinity of 15-20% of potential grain production due to poor pre-harvest practices and natural disasters and losses of up to 30% post-harvest due to inappropriate collection, transport, storage, pest control systems in Ethiopia (Ethiopia, 2016 pii).
Kenya	Kenya Strategy for Post-Harvest Loss Reduction 2018-2025	The strategy documents for PHL reduction in Kenya does not state the rationale behind the development of the strategy. The strategy notes in general that agriculture was identified in Kenya’s Vision 2030 as a key sector for achieving the envisaged annual economic growth rate. Neither does the Agriculture Sector Development Strategy nor the Food and Nutrition Security Policy nor the National Food Safety Policy (2013) of Kenya specifically, according to the PHL strategy, identify post-harvest loss management as a key constraint to food and security in the country.
Tanzania	National Post-Harvest Loss Management Strategy (2017-2027) – December 2017. Second Draft produced in December 2017 with the support of FAO.	Although the current policy environment is more receptive to the importance of PHL, the agriculture strategies have not paid adequate attention to PHL issues in an effort to increase food and income security (Tanzania 2017 p3).
Zambia	Post-harvest Management Strategy for Zambia (2018-2025) – March 2018. Draft Strategy prepared with the support of FAO and submitted in March 2018 for consideration by FAO.	In its second national agricultural policy released in 2016, Zambia recognized post-harvest losses as one of the main challenges that needs urgent attention (Nkonde et al 2018 p9).
Zimbabwe	Post-harvest management Strategy for Zimbabwe (2017-2025) – March 2018. Draft Strategy prepared with the support of FAO and submitted in March 2018	Zimbabwe currently does not have a standalone policy on Post-harvest loss management. Current policy frameworks include a few policy statements on PHL, particularly of the staple maize commodity (Zimbabwe 2018 p viii).

4.7.1 Overview of PHL in Africa:

Post-harvest loss strategy management is about bringing together all possible forms of approaches across the entire value chain that together contribute to reduced levels of losses occurring during and post harvesting of grains, fruits, vegetables, oilseeds, and all food crops, livestock and fisheries products. A study by [90] concluded that from a policy perspective, targeting PHL interventions to improve post-harvest handling techniques (especially those on the farm) is key to reducing PHL. They also concluded that scaling up these interventions must be based on a better understanding of the true extent of PHL. The use of nationally representative household survey data as a PHL measuring methodology is an important step in the right direction [91]. Besides improved storage and crop protection technologies there was a need for better market access and for higher post-primary education were crucial for PHL management [91]. These factors as alluded by [91], confirm the multi-dimensional nature of PHL but also the multi-disciplinary nature of management support that is required to deal with PHL.

Some of the major challenges found in relation to PHL management include [91]:

- knowledge of PHL magnitudes which currently is limited;
- inadequacies of loss of assessment methodologies that result in inaccurate PHL estimates
- The issue that losses are often economic rather than physical product losses yet that economic value of PHL is rarely known or calculated and
- Failure to address dynamics of supply chains by most technologies for loss mitigation.

Rigorous PHL assessment using systematic methodologies, as well as holistic approaches for losses mitigation are needed in the African continent [91].

4.7.2 Ending hunger in Africa by 2025:

According to the 2016 Global Hunger Index (GHI) Africa Edition produced by the International Food policy Research Institute, while the level of hunger in all countries across Africa, for which GHI scores could be calculated, has declined since 2000, the level of hunger in many countries remains unacceptably high with only three countries out of 42 African countries with scores that fall into the "low" hunger category, which 28 fall into the "serious" category and five countries have 2016 scores in the "alarming" category. A reduction in PHL, among other strategies to enhance the food and nutrition security in Africa, will go a long way to alleviating the huge hunger problem facing the continent.

By its nature and as revealed in many study works over the years, the target to half the current levels of PHL by 2025 calls for greater understanding and efforts towards the establishment of current levels of PHL in food crops. There is no real agreement at the national level as to the exact level of losses that are being experienced. To that effect, the Malabo Declaration target requires that extensive research and analytical work on PHL estimations be undertaken simply to establish the current levels of PHL against which the target of halving this level of losses can be applied. Other key issues that also emerge with analyzing country level losses include methods of post-harvest assessment and analysis which depend on the authority cited; financial support and investment into post-harvest lose reduction; as well as the political willingness and policy level awareness on PHL[41]

V. CONCLUSION

This research review found out that estimates from [21] suggest that as much as 37% of food produced in Africa is lost between production and consumption. These high estimates have motivated international attention to PHL. Yet interventions typically focus on improving on-farm grain storage techniques for small-scale farmers. The estimates use extrapolation from purposively sampled (and often older) case studies that may focus on areas where PHL is largest[94]. More and better quantification of (on-farm) grain loss is needed (which can then be compared with the costs of improved post-harvest practices). Also needed is a better understanding of farmers' behaviour in adopting improved post-harvest technologies.

Globally, energy in agriculture has concentrated on increasing food production (95% of research over the last fifty years was focused on improving production. A paltry 5% was directed to research on reduction of PHL. The consequences for this has been the loss and wasted food to the tune of 1.3 billion metric tonnes per year, worldwide. This is enough to feed 1.6 billion people annually. The cost of this is about US$2.6 trillion per year. To this add the ethical and environmental costs which are difficult to quantify.

PHL contribute to high food prices by removing part of the food from the supply chain. Although food availability and accessibility can be increased by upping production, improving distribution and reducing the losses. However, production resources including land, water and energy are limited and inelastic.

A major obstacle in achieving PHL mitigation is the lack of clear understanding of the real magnitude of PHL, which makes it impossible to measure progress against any loss reduction goals. Uncertain estimates of PHL, coupled with imprecise understanding of the points in value chains where the losses occur as well as the socio-economic factors for the losses could end in policy errors and sub-optimal choices of mitigation approaches.

VI. RECOMMENDATIONS

There are several implications for policymakers, farmer organisations and agricultural industries. First, policy makers might rethink the net social welfare impact of PHL and be very methodical when assessing the causes. The opportunity costs of mitigating loss appear to be a third critical component to causes, in addition to uncontrollable events and technical inadequacies. Second, policy goals of fixed levels of PHL may be unrealistic without a proper understanding of the management context facing farmers, especially a system of production that includes multiple cropping.

Below are a brief summary of recommendations to be taken note of:

- Reducing PHL presents a cost-effective opportunity to improve resource efficiency in the food system and help mitigate the risks of natural resource depletion. In addition, reducing PHL would ensure more sustainable use of resources thereby putting less pressure on ecosystems, including soils and water.
- Addressing fish losses and waste, including discards is necessary to reduce the impacts of fisheries on aquatic ecosystems.
- Food losses in low-income countries are often connected to the lack of access to energy, particularly in the post-harvest phase. In order to make the transition towards sustainable food value chains that reduce both food losses and fossil fuel dependence in food systems, it is necessary to upscale clean or low-carbon technologies. Increased deployment of the technologies that use renewable energy would improve the sustainability of food systems, while reducing losses in developing countries.
- Efforts that reduce PHL of food are essential to enhance global climate action because of their collective contributions to three overall objectives: mitigating climate change by reducing GHG emissions associated with PHL; strengthening resilience to cope with climate change and increasing net production output; PHL reduction measures, in the contest of resilient and low-emission food systems, should therefore be integrated into climate change strategies and action plans as additional opportunities towards achieving mitigation and adaptation objectives.
- Reducing the amount of food that is lost or wasted calls for harmonized policies and integrated food system approaches that consider all risks, challenges, opportunities and potential trade-offs. Creating an enabling environment requires a re-examination of existing policies and regulatory frameworks, including incentive schemes. Identifying policy gaps and ensuring policy coherence across sectors is key to inclusive pleasing processes for addressing the drivers and underlying causes of PHL.
- Bringing together governments, food producers and investors can help identify challenges and opportunities for addressing inefficiencies in food systems and accelerate the deployment of sustainable technologies in food value chains. Combining such efforts with sustainable practices and consumption patterns can pave way towards safeguarding environmental resources and ultimately needing the goals and targets set out in the 2030 Agenda for Sustainable Development. Emphasis must be targeted at improving access to finance, while encouraging appropriate policy incentives and building management capacities.

For the future of food in Africa the following are recommended [20] and [21]:

- Food production will have to increase by 60%, while adapting to climate change
- 80% of the necessary production increases must come from intensification and not from opening up new land.
- 70% of African population will live in urban centres; extending food value chains
- Loss reduction can be a more resource efficient response to food shortage than increased production.
- Silver lands of Zambia are working with smallholder farmer communities to help provide grain storage facilities (silos). They reckon that in Sub-Saharan Africa, around 30% of food is lost during handling and storage, this is compared to six per cent in North America. Poor storage facilities force farmers to often sell at hardest time when prices are at their lowest thus eroding their returns. Providing key storage infrastructure is essential to prevent PHL and ensure supply of quality grains.

VII. ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Human and Animal Rights

No animal/humans were used for studies that are base of this research.

Consent for Publication

Not applicable.

CONFLICT OF INTEREST

The author (Douglas Ncube PhD) certify that he has no affiliations with or involvement in any organisation or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership; employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

REFERENCES

[1] Aulakh, J. and Regmi, A. 2013. Post-Harvest Food Losses Estimation – Development of Consistent Methodology. In: Selected Poster Prepared for Presentation at the Agricultural and Applied Economics Association's 2013 AAEA and CAEs Joint Annual Meeting, Washington D.C.

[2] Alexandratos, N. and Bruinswa, J. 2012. World Agriculture Towards 2030/2050: The Saving Water. From Field to Fork-Curbing Losses and Westgate in the Food Chain 2012. Revision Working Paper: FAO: ESA No. 12-03, p4

[3] Rezaei, M. and Liu, M. 2017. Food Loss and waste in the Food Supply Chain. Food and Agriculture Organization of the United Nations.

[4] Grolleaud, M. 2002. Post-Harvest Losses: Discovering the Full Story. Overview of the Phenomenon of Losses During the Post-Harvest System. FAO Rome Italy.

[5] Kaminsk, J. and Christiaensen, L. 2011. Post-Harvest Loss in Sub Saharan Africa: What Do Farmers Say? Policy Research/Working Paper 6831. World Bank.

[6] Ambuko, Jane. 2017. Why Reducing Post-Harvest Losses is a Priority for Africa. The Conversation.

[7] Gustavasson, J., Cerderberg, C., Sonesson, U., van Otterdijk, R. and Meybeck, A. 2011. Global Food Losses and Food Waste: Extent Causes and Prevention. Rome. Food and Agriculture Organization of the United Nations.

[8] Mundial, B. 2008. Double Jeopardy: Responding to High Food and Fuel Prices.CumbreHokkaids-Toyako del G, 8,2.

[9] Trostle, R. 2010. Global Agricultural Supply and Demand: Factors Contributing to the Recent Increase in Food Commodity Prices. Rev DIANE Publishing.

[10] World Bank 2011. Missing Food: The Case of Postharvest Grain Losses in Sub-Saharan Africa. Washington, DC: The World Bank. 116p.

[11] Kader, A.A. 2005. Increasing Food Availability by Reducing Postharvest Losses of Fresh Produce. Acta Horticulture (IH5), 682, 2169-2176.

[12] Kader, A.A. and Roller, R.S. 2004. The Role of Post-Harvest Management in Assuring the Quality and Safety Horticultural Crops. FAO. Agricultural Services Bulletin 152, 52p

[13] WFLO 2010. Identification of Appropriate Postharvest Technologies for Improving Market Access and Incomes for Small Horticultural Farmersin Sub Sahara Africa and South Asia. WFLO Grant Final Report to the Bill and Melinda Gates Foundation, March 2010. 318 pp.

[14] Vermeulen, S.J., Campbell, B.M. and Ingram, J.S.I. 2012. Climate Change and Food Systems. Annu. Rev. Environ. Resources. 2012. 37:195-222

[15] Buzby, J.C. and Hyman, J. 2012. Total and per Capita Value of Food Loss in the United States. Food Policy, 37(5), 561-570

[16] Hodges, R. J., Buzby, J.C. and Bennett, B. 2011. Postharvest Losses and Waste in Developed and less Developed Countries: Opportunities to Improve Resource Use. Journal of Agricultural Science. 149:37-45. Cambridge University Press 2010

[17] Scwab, J. 2010. Environmental Protection Agency (EPA). Office of Solid Waste and ??? Fox, T. and Fimeche, C. 2013. Global Food Waste Not, Want Not. IMechE. England and Wales,

[18] Fox, T and Fimeche, C. 2013. Global Food Waste Not, Want Not. IMechE. England and Wales.

[19] Farming First 2019. Actions in Africa Preventing Food Loss and Waste. FANRPAN.

[20] World Bank, Natural Resources Institute and FAO. 2011. Missing Food: The Case of Postharvest grain Losses in Sub-Saharan Africa. Available at: http://siteresources.worldbank.org/INTARD/Resources/MissingFoods10web.pdf Assessed on 19/01/2025.

[21] FAO 2011. Global Food Losses and Food Waste – Extent Causes and Prevention. Rome. Available online: http://www.fao.org/docrep/014/mb060e/.pdf Accessed 21/04/2025.

[22] FAO 2014. Global Initiative on Food Loss and Waste Reduction Definition Framework of Food Loss, Working Paper, 27 February 2014

[23] Parfitt, J., Barthel, M. and MacNaughton, S. 2010. Food Waste within Food Supply Chains: Quantification and Potential for Change to 2050, Phil. Trans. Soc., Vol. 365, pp 3065-3081.
[24] De Lucia, M and Assennato, D. 1994. Agricultural Engineering in Development – Post-harvest Operations and Management of Food Grains. FAO Agricultural Services, Bulletin No. 93.
[25] Hodges, R.J., Buzby, J. C. and Bennett, B. 2010. Postharvest losses and waste in developed and less developed countries: opportunities to improve resource use. The Journal of Agricultural Science, 149 (SI). Pp37-45. ISSN 0021-8596.
[26] Aulakh, J., Regmi, A., Fulton, J. R. and Alexander, C. 2013. Estimating post-harvest food losses: developing a consistent global estimation framework. In: Proceedings of the Agricultural and Applied Economics Association's 2013 AAEA and CAES joint annual meeting. Washington, D.C., USA, 4-6 August 2013.
[27] Kader, A. A. 2002. Postharvest Technology of Horticultural Crops. 3rd ed. University of California. Agricultural National Resources, Oakland, Publication 3311.
[28] Kiaya, Victor. 2014. Post-Harvest Losses and Strategies to Reduce Them. Technical Paper. Scientific and Technical Department. ACF International.
[29] Kitinoja, L. and Gorny, J.R. 1999. Postharvest Technology for Small-scale Produce Marketers: Economic Opportunities, Quality and Food Safety. University of California. Postharvest Horticulture Series No. 21.
[30] Stuart, T. 2009. Waste – Uncovering the Global Food Scandal. Penguin Books: London, ISBN=978-0-141-03634-2.
[31] FAO 2011. Global Food Losses and Food Waste – Extent, Causes and Prevention. Rome. Available at www.fao.org/docrep/014/m6060e/mb060e00.pdf Accessed 28/04/2025
[32] Kitinoja, L. and Gorny, J. R. 1999. Postharvest technology for small-scale produce marketers: economic opportunities, quality and food safety. Postharvest Horticulture Series No. 21. Postharvest Technology Center Uni. California, Davis.
[33] Gross, K., Wang, C. Y. and Saltveit, M. E. 2002. The commercial storage of fruits, vegetables and florist and nursery stocks. USDA Agr. Handbook 66.
[34] Atanda, S.A., Pessu, P.O., Agoda, S., Isong, U. and Ikotun, M. 2011. The Concepts and Problems of Postharvest Food Losses in Perishable Crops. African Journal of Food Sciences. Vol. 5(11) pp 603-613, 15 October 2011
[35] FAO, 1983. Food Loss Prevention in Perishable Crops. Available athttp://www.fao.org/docrep/s8620e/06.htm Accessed on 04/04/2025
[36] Rolle, R.S. 2006. Improving Postharvesting Management and Marketing in the Asia-Pacific Region: Issues and Challenges. From: Postharvest Management of Fruit and Vegetables in the Asia-Pacific Region, APO, ISBN: 92-833-7051-1
[37] Choudhury, M.I. 2006. Recent Developments in Reducing Postharvest Losses in the Asia-Pacific Region. In Postharvest Management of Fruit and Vegetables in Asia-Pacific Region, APO, ISBN: 92-833-7051-1
[38] SEPA. 2008. Svinn/Livsmedelskedjan-mojligheter. Till MinstaderMangder. Swedish Environmental Protection Agency, Bromma, Sweded, ISBN978-91-620-5885-2
[39] Purin, M. 2016. How Access to Energy can Influence Losses. Rome FAO.
[40] Wareing, P. 2002. Pests of Durable Crop-moulds. In Crop Post-harvest: Science and Technology Volume 1: Principles and Practice (Editors, P. Golob, G. Farrell and J.F. Orchard, pp120-130. Oxford: Blackwell. Sciences Ltd.
[41] Lipinski, B., Hanson, C., Lomax, J., Kitinoja, L., Waite, R. and Searchinger, T. 2013. Reducing Food Loss and Waste. World Resources Institute Working Paper.
[42] FAO 1980. Assessment and Collection of Data on Post-harvest Good Grain Losses, FAO Economic and Social Development Paper 13. Rome.
[43] Presentation by FANRPAN during AU-FAO Post-Harvest Regional Workshop, Nairobi, Kenya, 24 – 25 July 2018.
[44] African Union Commission 2018. Post-Harvest Loss Management Strategy.
[45] Searchinger, T., Henson, C., Ranganathan, J., Lipinski, R., Waite, R., Winterbottom, A., Dinshaw, A. and Heimlich, R. 2013. The Great Balancing Act. Working Paper, Instalment 1 of Creating a Sustainable Food Future. Washington, D.C: World Resources Institute. Accessible at: www.worldresourcesreport.org Accessed 10/05/2025.
[46] FAO, 2011a. Energy-smart Food for People and Climate. FAO of the UN. Rome Italy.
[47] IMechE, 2014. A Tank of Cold: Cleantech Leapfrog to a more Food Secure World. Institute of Mechanical Engineers, London England.
[48] FAO, 2011b. State of World's Land and Water Resources for Food and Agriculture: Managing Systems at Risk. FAO of the UN, Rome, Italy.
[49] Practical Action, 2014. Poor People's Energy Outlook 2014: Key Messages on Energy for Poverty Alleviation. Rugby, UK. Practical Action Publishing.
[50] Popat, M., Griffith, G., Mounter, S. and Cacho, O. 2020. Postharvest Losses at the Farm Level and its Economy-wide Costs: The Case of the Maize Sector in Mozambique.
[51] FAO 2015a. Post 2015 and SDGs: Nourishing People, Nurturing the Planet. Rome. Available at www.fao.org/3/-az775e.pdf Accessed 30/05/2025
[52] FAO 2013. Food Wastage Footprint. Impacts on Natural Resources. Summary Report. Rome.
[53] Wieben, Emille. 2016. The Post-2015 Development Agenda: How Food Loss and Waste Reduction can Contribute Towards Environmental Sustainabilty and Achievement of the Sustainabale Development Goals. DNC, Working Paper. Volume No. 1 2016 ISBN 9783944863429.

[54] HLPE 2014. Food Losses and Waste in the Context of Sustainable Food Systems. A Report by the High-Level Panel of Experts in Food Security and Nutrition of the Committee on World Food Security. Rome, FAO. Available at www.fao.org/3/a-i3901e.pdf Accessed 20/05/2025

[55] FAO 2015b. Food Wastage Footprint and Climate Change. Rome. Available at www.fao.org/3/a-bb144.e.pdf Accessed 01/06/2025

[56] Weingart, J. and Giovannucci, D. 2004. Rural (Renewable) Energy: A Practical Primer for Productive Applications. ESMAP Department. World Bank.

[57] Gustavsson, J., Cederberg, C., Sonesson, U. and Emanuelsson, A. 2013. The Methodology of the FAO Study: Global Food Losses and Food Waste-extent, Causes and Prevention. Gothenburg, Sweden: The Swedish Institute for Food and Biotechnology 70.

[58] FAO, 1996. Rome Declaration on World Food Security and World Food Summit Plan of Action. Rome, World Food Summit.

[59] FAO, 2014a. Food Wastage Footprint: Full-cost Accounting. Fuel Report. Rome.

[60] West, P.C., Gerber, J.S., Mueller, N.D., Brauman, K.A., Carlson, K.M., Cassidy, E.S., Engstrom, P.M., Johnson, M., MacDonald, G.K., Ray, D.K. and Siebert, S. 2014. Leverage Points for Improving Global Food Security and the Environment. Science, 345 (^194): 325-328

[61] Nanda, S.K., Wishwakarma, R. K., Bathla, H. V. L., Rai, A. and Chandra, P. 2012. Harvest and Post-Harvest Losses of Major Crops and Livestock Produce in India. India Council of Agricultural Research (ICAR) Publication: New Dehli

[62] Affognon, H., Mutungi, C., Sanginga, P. and Borgemeister, C. 2014. Unpacking Postharvest Losses in Sub Saharan Africa: A Meta-Analysis. World Development Vol 66, pp 49-68. Publisher: Elseivier Ltd.

[63] GIZ Deutsche Gesellschaft fur InternationaleZusammenarbert GmbH 2013a. Reducing Postharvest Losses Conserves Natural Resources and Saves Money. Report of GFFA Export Panel discussion held o 18 January 2013 in Berlin, 30p

[64] FAO-World Bank 2010. Reducing Post-harvest Losses in Grain Supply Chains in Africa. Report of FAO-World Bank Workshop held from 18-19th March 2010 in Rome, Italy. 120p.

[65] GZI Deutsche Gesellschat fur InternationaleZusammenarbeit GmbH. 2013b. The Ecological Footprint of Cassava and Maize Postharvest Losses in Nigeria. A Life Cycle Assessment, Eschborn: GIZ, 48p.

[66] Kader, A.A. 2005. Increasing Food Availability by reducing Postharvest Losses of Fresh Produce. Acta Hortic. 682, 2169-2176.

[67] Lundgvist, J., de Fraiture, C. and Molden, D. 2008. Saving Water: from Field to Fork – Curbing Losses and Wastage in the Food Chain. In SIWI Policy Brief. Stockholm, Sweden: SIWI.

[68] Prusky, D. 2011. Reduction of the Incidence of Postharvest Quality Losses and Future Prospects. Food Security, 3(4). 463-474.

[69] Adegbola, P.V. 2010. Economic Analyses of Maize Storage Innovations in Southern Benin. Unpublished Doctoral Thesis, Wageningen University, The Netherlands.

[70] Harris, K.L. and Lindbald, C.J. 1978. Postharvest Grain Loss Assessment Methods – A Manual of Methods for the Evaluation of Postharvest Losses. Minnesota: American Association of Cereals Chemists.

[71] Alonso-Amelot, M.E. and Avila-Nunez, J.L. 2011. Comparison of Seven Methods for Stored Cereal Losses to Insects for their Application in Rural Conditions. Journal of Stored Products Research. 47(2), 82-87.

[72] Compton, J.A.F. and Sherrington, J. 1999. Rapid Assessment Methods for Stored Maize Cobs: Weight Losses due to Insect Pests. Journal of Stored Products Research. 35(1), 77-87.

[73] Compton, J.A.F., Floyd, S. Magrath, P.A., Addo, S., Goedevi, S.R., Agbo, B. 1998. Involving Grain Traders in Determining the Effect of Postharvest Insect Damage on the Price of Maize in African Markets. Crop Protection. 17(6), 483-489.

[74] Ngatia, C.M. and Mutambuki, K. 2011. Comparison of Three Methods of Weight Loss Determinations on Maize Stored in Two Farmer Environments Under Natural Infestation. Journal of Stored Products and Postharvest Research, 2(13), 254-260.

[75] Akande, G. and Diei-Ouadi, Y. 2010. Postharvest Losses in Small-scale Fisheries: Case Studies in Five Sub-Saharan African Countries. FAO Fisheries and Aquaculture Technical Paper No. 550. Rome, FAO.

[76] Kitinoja, L., Saran, S., Roy, S.K. and Kader, A.A. 2011. Postharvest Technology for Developing Countries: Challenges and Opportunites in Research, Outreach and Advocacy. Journal for Science, Food and Agriculture, 91(4), 597-603.

[77] Alderman, H. and Shively, G. 1996. Economic Reform and Food Prices: Evidence from Markets in Ghana. World Development, 24(3), 521-534.

[78] Kearney, J. 2010. Food Consumption Trends and Drivers. Philosophical Transactions of the Royal Society B, 365 (1554) (2010), pp 2793-2807.

[79] Kader, A.A. 2004. The Role of Post-harvest management in Assuring the Quality and Safety of Horticultural Produce. FAO Agricultural Services Bulletin 152. Available at www.fao.org/docrep/007/y5431e00.htm Accessed 02/02/2025

[80] Daniel, J.H., Lewis, L.W., Redwood, Y.A., Kieszak, S., Brieman, R.F. and Flanders, W.D. 2011. Comprehensive Assessment of Maize Aflatoxin Levels in Eastern Kenya. 2005-2007 Environmental Health Perspectives, 119(12), 1794-1799.

[81] Juma, G.P., Battenweck, I. Drucker, A.G., and Ngigi, M. 2007. Consumption of and Willingness to Pay for Indigenous Small Ruminants Meat in Marsabit, Kenya. Available at http://egspace.cgiar.org/handle/10568/1204Accessed on 23/03/2025

[82] Langyintuo, A.S., Ntoukam, G., Murdock, L., Lowenberg-DeBoer, L. and Miller, D.J. 2004. Consumer Preferences for Cowpeas in Cameroon and Ghana. Agricultural Economics, 30(3), 203-213.

[83] Mishili, F.J., Fulton, J., Shehu, M., Kushwaha, S., Marfo, K. and Jamal, M. 2007. Consumer Preferences for Quality Characteristics along the Cowpea Value Chain in Nigeria, Ghana and Mali. Working Paper No.06-17. Department of Agricultural Economics. Purdue University. Available at http://ageconsearch.umn.edu/bitstream/28684/1/wp060017.pdf Accessed on 04/03/2025

[84] Biswas, S. L. 2013. Present Status of Pre and Post-Harvest Research and Extension Activities of Vegetable Seeds in BRAC. 2013. BRAC Agriculture Research and Development Centre, Gazipur, Bangladesh.

[85] Bekele, D. 2018. Review on Factors Affecting Postharvest Quality of Fruits. J. Plant Sci; Res. 2018; 5(2): 180

[86] John, P.J. 2018. Handbook on Post Harvest Management of Fruits and Vegetables. Daya Publishing House.

[87] Bloom, J. 2010. American Wasteland. Da Capo Press, Cambridge, MA, USA

[88] Verghese, K., Lewis, H., Lockery, S. and Williams, H. 2013. FINAL REPORT: The Role of Packaging in Minimising Food Waste in the Supply Chain of the Future. Centre for Design RMIT University. Melbourne, Australia.

[89] U.S. Department of State. 2013. Postharvest Loss Challenges – Discussion Paper. Office of Agriculture, Biotechnology and Textile Trade Affairs Bureau of Economics and Business Affairs. U.S. Department of State.

[90] Christiaensen, L and Demery, L. eds. 2018. Agriculture in Africa: Telling Myths from Facts. Directions in Development. Washington, D.C: World Bank. Doi:10.1596/978-1-4648-1134.O.License:Creative Commons Attribution cc BY3.0IGO-WB publication 2018.

[91] Sheahan, M. and Barrett, C.B. 2017. Review: Food Loss and Waste in Sub-Saharan Africa, Food Policy 70 (2017) 1-12. Published by Elsevier, Science Direct Journal.

Assessment of Urdbean Disease Incidence in Rice Fallow Systems of Krishna District, Andhra Pradesh

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Abstract— *This study focuses on the surveillance of major diseases affecting urdbean (blackgram) cultivated in rice fallows within the Krishna district of Andhra Pradesh. The research is driven by the significant yield losses caused by major diseases in this region. The primary objective is to assess the impact of these diseases on crop yields to develop effective management strategies. A roving survey was conducted in farmers' fields during the rabi 2022-23 season, with data collected on disease incidence and severity for various pathogens, including Yellow Mosaic Virus (YMV), leaf crinkle, leaf curl, stem canker, leaf spots, and powdery mildew. Results from the Rabi 2022-23 survey revealed varying levels of disease prevalence across different villages and crop stages. The incidence of Mungbean Yellow Mosaic Virus (MYMV), measured on a 1-9 scale, ranged from 1 to 5. The percentage of leaf crinkle incidence varied from 1.63% to 11.54%. Leaf spots were rated on a disease scale of 1-9, with scores ranging from 3 to 6. Powdery mildew severity, assessed on a 0-5 scale, ranged from 2 to 3. The percent incidence of leaf curl was found to be between 0% and 2.81%, while stem canker incidence ranged from 2.18% to 27.73%. The findings of this research indicate that diseases such as powdery mildew, Corynespora leaf spot, leaf crinkle, MYMV, and stem canker are all contributing to yield losses in blackgram.*

Keywords— Blackgram, MYMV, ULCV, leaf curl, powdery mildew, Corynespora leaf spot, and stem canker.

I. INTRODUCTION

Urdbean [*Vigna mungo* (L.) Hepper], also known as blackgram is a short-duration pulse crop often grown in rice-fallow systems in many parts of Asia. Urdbean is suitable for rice fallow situations due to its ability to thrive in residual moisture and its short duration. Specifically, sowing urdbean immediately after rice harvest, potentially with an increased seed rate, can be an effective strategy for maximizing yields and profitability in these systems. Despite immense scope, the extensive use of rice fallows for pulse cultivation is mostly restricted because of several biotic, abiotic and socio-economic constraints (Pande *et al.*, 2000). Among the biotic constraints, several fungal, viral diseases, insect pests and nematodes constraint both cool season and warm season pulses production in rainfed rice fallow lands (Pande *et al.*, 2012).

Krishna district, located in the coastal region of Andhra Pradesh, is recognized for its fertile lands and extensive rice cultivation. Consequently, urdbean is a major *rabi* (post-monsoon) crop in the district, thriving in the black cotton soils that retain moisture effectively. In rice fallow areas urdbean and mungbean are susceptible to *Mungbean Yellow Mosaic Virus* (*MYMV*), besides they are susceptible to powdery mildew, cercospora leaf spot and also to leaf curl virus (Narendra *et.al.*, 2018). An in-depth understanding of disease incidence is critical for enhancing urdbean (*Vigna mungo*) productivity, particularly within the rice fallow pulse systems of Krishna District, Andhra Pradesh. This research helps in reporting the findings of a survey conducted to identify and assess the prevalence and severity of major diseases affecting urdbean cultivated under rice-fallow conditions in Krishna district, Andhra Pradesh during rabi 2022-23.

II. MATERIALS AND METHODS

2.1 Survey Area and Period:

The survey was conducted during the *Rabi* season under rice fallows of Krishna district, Andhra Pradesh during 2022-23.

2.2 Sampling Procedure:

Roving survey was conducted in prominent urdbean growing mandals (administrative divisions) of Krishna district, Andhra Pradesh. The selection of mandals was based on the reported area under urdbean cultivation in rice fallows. The survey was carried out during the rabi season (typically from November to March), when urdbean is predominantly grown as a rice-fallow crop. Multiple visits were made to the selected fields at different crop growth stages (vegetative, flowering, pod formation and pre harvesting) to capture the complete spectrum of disease incidence. Varieties cultivated in farmers' fields, such as LBG 752, LBG 645, LBG 648, LBG-787, TBG-104, PU-31, and Thutakuminumu, were observed. The plants were visually inspected for characteristic symptoms of various diseases.

2.3 Disease Incidence and Severity Assessment:

Disease severity was assessed using standard disease rating scales specific to each disease.

- Yellow mosaic Disease (YMV): 1-9 scale given by Alice and Nadarajan, (2007)
- Powdery mildew: 0-5 scale
- Leaf spots: 1-9 scale
- Leaf Curl: Percent Disease Incidence
- Leaf crinkle: Percent Disease Incidence
- Stem canker: Percent Disease Incidence

The percent disease incidence was calculated using the formula:

$$\text{Percent Disease Incidence (PDI)} = \frac{\text{Number of infected plants}}{\text{Total number of plants}} X100 \quad (1)$$

2.4 Data Analysis:

The collected data on disease incidence and severity were tabulated and analysed to determine the prevalence of each disease across the surveyed mandals and villages. Mean incidence and severity percentages were calculated for each disease.

III. RESULTS AND DISCUSSION

The survey revealed the presence of several economically important diseases affecting urdbean cultivation under rice-fallow conditions in Krishna district. The major diseases observed were *Mungbean Yellow Mosaic Virus* (*MYMV*), *Urdbean Leaf Crinkle Virus* (*ULCV*), Powdery Mildew, Corynespora Leaf Spot, and Stem Canker. The prevalence and severity of these diseases varied across the surveyed locations and depending on the crop growth stage. The major diseases identified on blackgram during surveys undertaken in rice fallow situation for *Rabi*, 2022-23, in various mandals and villages of Krishna district were presented in Table 1.

3.1 Mungbean Yellow Mosaic Virus (MYMV):

The incidence of *MYMV* ranged from 1 to 5 on a scale of 1-9. As observed in Table 1, *MYMV* incidence was present across all surveyed mandals and villages, with some fields showing higher severity (e.g., Puchagadda, Kodali, Pooshadam, Movva, Ayyanki, Penjendra, Pamarru, Ayyanki in Pamarru). This indicates that *MYMV* is a prevalent disease in urdbean cultivated under rice fallows in Krishna district. This finding aligns with observations in other urdbean-growing regions of Andhra Pradesh, including Guntur district, where *MYMV* is a major constraint (Kasi Rao *et al.*, 2021; Bhaskar *et al.*, 2022). The transmission of *MYMV* by whiteflies (*Bemisia tabaci*) is a major factor contributing to its rapid spread in the field (Prasada

Rao *et al.,* 2003; Biswas *et al.,* 2009). The availability of alternate weed hosts and favorable environmental conditions (temperature and humidity) likely contributed to its high prevalence.

TABLE 1
MAJOR DISEASES IDENTIFIED ON BLACKGRAM DURING SURVEYS UNDERTAKEN IN RICE FALLOW SITUATION FOR RABI, 2022-23 ARE FURNISHED HEREUNDER

Mandal	Village	Variety	Stage of the crop	*MYMV* (1-9 scale)	Leaf Crinkle	Leaf Curl	Stem canker	Corynespora Leaf spots (1-9 scale)	Powdery Mildew (0-5 scale)
					(% Incidence)				
Ghantasala	Ghanatsala	LBG 752	Vegetative Stage	3	11.54	2.16	13.42	5	3
	Puchagadda	LBG 645	Vegetative Stage	5	5.15	1.08	5.12	4	2
	Devarakota	LBG 752	Vegetative Stage	3	3.27	1.73	9.25	4	3
	Kodali	LBG 752	Pod development stage	5	7.21	0.00	3.45	5	3
	Pooshadam	LBG 645	Pod development stage	5	12.34	0.00	12.34	6	2
	Daliparru	Thutikada minumu, LBG 752	Pod development stage	3	4.37	1.24	18.72	6	3
Challapalli	Challapalli	LBG 752	Pod development stage	3	2.71	0.00	15.91	4	2
	Nadakuduru	VBN 8	Pod development stage	1	1.63	0.00	12.42	5	2
	Vakkalagadda	LBG 752	Pod development stage	3	4.16	1.85	5.36	4	2
Movva	Movva	LBG 645	Flowering stage	5	16.24	2.81	7.19	4	2
	Kuchipudi	LBG 752	Flowering stage	3	12.11	1.23	13.45	5	3
	Penumacha	LBG 752	Flowering stage	3	2.19	0.00	12.27	4	1
	Ayyanki	LBG 648	Flowering stage	5	7.84	1.24	10.34	3	2
Gudlavalleru	Gudlavalleru	LBG 752	Flowering stage	3	6.54	1.87	11.36	2	3
	Venuthurumilli	Thutikada minumu	Flowering stage	3	4.36	2.15	27.73	2	3
	Dokiparru	LBG 787	Flowering stage	3	1.45	0.00	14.21	4	3
	Penjendra	LBG 752	Flowering stage	5	9.41	0.00	21.28	3	3
Pedana	Nandigama	PU 31	Flowering stage	1	8.54	0.00	18.75	3	1
	Nadupuru	TBG 104	Flowering stage	1	4.78	0.00	7.32	4	2
Machilipatnam	Arisepalli	LBG 752	Flowering stage	3	3.72	1.26	12.72	5	1
	Patha Majeru	LBG 645	Flowering stage	5	2.51	0.00	19.36	6	1
Pamarru	Pamarru	LBG 648	Pod development stage	5	11.23	0.00	6.24	5	2
	Syamalapuram	VBN 8	Pod development stage	3	7.34	1.56	2.18	5	2
	Ayyanki	LBG 645	Pod development stage	5	8.15	2.36	5.12	6	2
	Ainampudi	LBG 752	Pod development stage	3	7.16	2.09	12.53	4	3

3.2 Urdbean Leaf Crinkle Virus (ULCV):

The percent incidence of Leaf Crinkle ranged from 1.45% to 16.24%. The highest incidence was observed in Movva (16.24%) during the flowering stage. This indicates that *ULCV* is a significant viral disease affecting urdbean in the region. Early infection of plants with *ULCV* resulted in more severe symptoms and greater yield losses (Chowdhury and Nath, 1983). The seed-borne nature of *ULCV* (Biswas *et al.,* 2009) and potential mechanical transmission, along with vector transmission, likely contribute to its spread in rice-fallow systems.

3.3 Leaf Curl:

The incidence of leaf curl disease varied from 0% to 2.81% across different locations, with the highest occurrence observed in Movva at 2.81%. Although relatively lower in prevalence compared to other diseases, it is still important to address its presence. This study was supported by Prasada Rao *et al.,* 2003 who reported that the incidence of leaf curl on urdbean was observed to be between 2.92% and 5.73% in rice fallows of Guntur and Krishna districts during rabi 2001-02.

3.4 Stem Canker:

The percent incidence of stem canker ranged from 2.18% to 27.73% in different villages of Krishna district under rice fallow condition. The highest incidence was recorded in Venuthurumilli (27.73%). This indicates that stem canker is a significant factor affecting blackgram yields in the region. According to Jacob, P.S. and Jhansi, K. (2020) 22.32% disease incidence was observed in farmers practice.

3.5 Corynespora leaf Spots (including *Corynespora cassiicola*):

Leaf spots ranged from 2 to 6 on a disease rating scale of 1-9. The highest severity was observed in Pooshadam, Daliparru, Patha Majeru, and Ayyanki (Pamarru). This suggests that leaf spot diseases, including Corynespora leaf spot, are consistently present and can cause considerable damage. Alternaria leaf spot has been reported to cause varying degrees of severity in urdbean in Andhra Pradesh (Ambarish *et al.,* 2021).

3.6 Powdery Mildew (*Erysiphe polygoni*):

Powdery mildew ranged from 1 to 3 on a severity scale of 0-5. While generally not as severe as viral diseases, its consistent presence across different villages indicates its widespread occurrence. Warm and humid conditions typically favour the development of powdery mildew (Prathyusha *et al.,* 2021). The presence of thick crop canopy in well-grown urdbean fields under rice fallows might create a conducive microclimate for the disease.

IV. CONCLUSION

The survey confirms that several major diseases, including *MYMV*, Leaf Crinkle, Powdery Mildew, Leaf Spots, and Stem Canker, significantly affect urdbean yields under rice-fallow conditions in Krishna district. These fungal, bacterial, and viral diseases are considerably contributing to yield reduction. The results suggest that continuous monitoring of these diseases could aid in developing a disease forecasting system that farmers could adopt for timely management of diseases.

REFERENCES

[1] **Alice, D., and Nadarajan, N., 2007).** Pulses: Screening techniques and assessment for disease resistance. *All India Coordinated Research Project on MULLaRP*, Tamil Nadu Agricultural University. Kasturi Graphics and Printers, Coimbatore, 24.

[2] **Ambarish, S., Prathyusha, K., Sujatha, K., & Sreeramulu, M. 2021.** Identification of sources of resistance to Alternaria leaf spot of blackgram. Biological Forum – An International Journal, 13(1), 261-269.

[3] **Bhaskar, A. V., Prathyusha, K., Sujatha, K., & Sreeramulu, M., 2022.** Identification of Sources Resistance to Leaf Spot, Powdery Mildew, Mungbean Yellow Mosaic Virus and Leaf Crinkle Virus Diseases in Blackgram. *Research Trend, 13*(1), 162-171.

[4] **Biswas, K., Khetarpal, R. K., & Sharma, M. 2009.** Seed transmission of Urdbean Leaf Crinkle Virus (*ULCV*) in urdbean. *Indian Journal of Virology*, *20*(2), 147-149.

[5] **Chowdhury, A. K., & Nath, P., 1983.** Studies on Urdbean Leaf Crinkle Virus. Plant Disease Research, 1(1), 60-65.

[6] **Jacob, P.S. and Jhansi, K., 2020.** Stem canker management in rice fallow rabi blackgram in Krishna district of Andhra Pradesh. *Journal of Pharmacognosy and Phytochemistry*, 9(5): 1993-1996

[7] **Kasi Rao, M., Prathyusha, K., Sujatha, K., & Sreeramulu, M., 2021.** Prevalence of Viral diseases of Urdbean in Guntur District of Andhra Pradesh. *Biological Forum – An International Journal*, *13*(1), 261-269.

[8] **Narendra, K., Arti, Y., Saumya, S. and Yadav, S.L.**, 2018. Growing Pulses in Rice Fallow: Ensuring Nutritional Security in India. *Conservation Agriculture for Advancing Food Security in Changing Climate*1 (20, 18): 107-122.

[9] **Pande, S., Sharma, S. B., & Ramakrishna, A., 2000.** Biotic stresses affecting legumes production in the Indo-Gangetic Plain.

[10] **Pande, S., Sharma, M., Ghosh, R., Rao, S. K., Sharma, R. N., & Jha, A. K.**, **2012.** Opportunities for Chickpea Production in Rainfed Rice Fallows of India. Baseline Survey Report.

[11] **Prasada Rao, R. D. V. J., Singh, S. J., & Kulkarni, S., 2003.** Characterization and management of Mungbean Yellow Mosaic Virus infecting soybean and urdbean. *Journal of Mycology and Plant Pathology*, *33*(1), 105-110.

[12] **Prathyusha, K., Ambarish, S., Sujatha, K., & Sreeramulu, M., 2021.** Prevalence of Viral diseases of Urdbean in Guntur District of Andhra Pradesh. Research Trend, 13(1), 261-269.

Eco Friendly Management of Anthracnose of Black Gram

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Abstract— *With an objective to find out the non-chemical alternative to manage the Colletotrichum lindemuthianum (L), infecting anthracnose disease in black gram [Vigna mungo (L.) Hepper] in vitro condition during the year 2021-23. Different antagonist bio-agents viz. Trichoderma viride, T. harzianum, Pseudomonas fluorescens and Bacillus subtilis were evaluated by dual culture technique as well as efficacy of different organic inputs and phytoextracts viz. panchagavya, jivamrutha, cow urine, vermiwash, neem leaf extract, ginger rhizome extract, garlic bulb extract, datura leaf extract were tested in vitro by using poisoned food technique against C. lindemuthianum. The result indicated that among the in vitro tested fungal and bacterial antagonist, T. viride showed maximum growth inhibition of 60.48 per cent which was followed by T. harzianum (50.19%). Among eight organic inputs and phytoextracts, the highest mean growth inhibition of 60.99 per cent was recorded with panchagavya which was followed by jivamrutha (57.17%) whereas in pot condition vermiwash at 10 per cent gave highest per cent disease control (57.20%) followed by garlic bulb extract at 10 per cent (51.19%).*

Keywords— Black Gram, Anthracnose, Bio-Agents, Organic Inputs, Phytoextracts.

I. INTRODUCTION

The black gram [*Vigna mungo* (L.) Hepper] commonly known as urdbean, is an annual semi erect to spreading herb belonging to the family *Leguminosae*. Black gram is locally known as Urad dal (Hindi), Minumulu (Telgu), Ulundu Paruppu (Tamil), Uddina bele (Kannada), Masakalai dala (Bengali), Biri dali (Oriya), Adad dal (Gujrat), Kali dal, Udid (Marathi) in India. It has been growing in India, Pakistan, Bangladesh, Sri Lanka, Thailand, Vietnam, Indonesia, South China and Malaysia since ancient times. India is said to be the origin of black gram (Piper and Morse, 1914). India as the primary Urd bean origin centre with Central Asia as a secondary location (Vavilov, 1926). Black gram has high nutritional value containing, fat (1.4%), protein (24%), carbohydrate (59.6%), calcium (154 mg), phosphorus (385 mg), iron (9.1 mg), thiamine (0.4 mg), riboflavin (0.37 mg), niacin (2 mg) and beta carotene (38 mg) per 100 g seeds (Gopalan *et al.* 1971). It is a nutritive fodder for animals, especially milch animals. The leaves and stems are the most common sources of fodder, but seeds, pods and pod husks are also used. Black gram crop is itself a mini-fertilizer factory, as it has unique characteristics of maintaining and restoring soil fertility through fixing atmospheric nitrogen through symbiotic association with *Rhizobium* bacteria, which are present in the root nodules. Black gram can fix atmospheric nitrogen to the tune of 30 kg nitrogen per hectare per year. Black gram can be used as green manure and a cover crop. The crop is suitable for intercropping with different crops such as sorghum, cotton, pearl millet, green gram, maize, groundnut and soybean for increasing production and maintaining soil fertility (Parashar, 2006). India is the world's leading producer of black gram, accounting for more than 70 per cent of global output, followed by Myanmar and Pakistan (Anon., 2020). In India, the black gram area increased by 386 per cent in *Kharif* 2020-21, from 1.88 lakh ha in 2019-20 to 8.77 lakh ha in 2020-21. Madhya Pradesh (4.45 lakh ha), Maharashtra (1.79 lakh ha), Rajasthan (0.71 lakh ha), Karnataka (0.58 lakh ha), Telangana (0.11 lakh ha) and Andhra Pradesh (0.04 lakh ha) are the major *kharif* growing states (Anon., 2020). In Gujarat, black gram is primarily grown in the *kharif* season in the Kutch, Banaskantha, Saurashtra, Mahesana and Panchmahal districts, with adequate but erratic rainfall. During the summer, however, it is grown extensively in the districts of Kheda, Vadodara and Panchmahal (Anon., 2020).

Biotic and Abiotic stresses cause significant yield reduction in black gram. Among the various fungal diseases, the occurrence of anthracnose disease in black gram is commonly observed in most of the cultivated areas. Anthracnose continues to be one of the major constraints in black gram cultivation caused by *Colletotrichum* spp. is world's most important seed and soil-borne disease. At least four species of *Colletotrichum* have been found associated with green gram and black gram causing anthracnose in different parts of the world (Saxena and Sinha, 1977). It has been reported to possess high pathogenic variability and more than 100 races of *C. lindemuthianum* have been identified worldwide (Sharma *et al.*, 2007). Anthracnose pathogen (*Colletotrichum* spp.) attacks all aerial parts of plants at all stages of development. Symptoms are black, circular, sunken spots with a dark centre and bright red-orange margins appear on leaves and pods. The cotyledons of seedlings show dark brown to black sunken spots, which may bear pink spore masses of the fungus in wet weather and become blighted due to infection shortly after seed germination. In the event of a severe infection, the affected parts, particularly the leaves, wither. The pathogen perennates on infected seeds and in the soil on diseased plant debris. The secondary infection takes place through airborne conidia. The disease is most common in areas with cool and wet weather and it can result in a yield loss of up to cent per cent. Various researchers have estimated yield losses due to anthracnose between 24 to 67 per cent (Deeksha and Tripathi, 2002), 18.2 to 86.6 per cent (Laxman, 2006) and 21.36 to 60.07 per cent (Kulkarni, 2009).

II. MATERIALS AND METHODS

2.1 Antagonistic effect of different bio-agents against *C. lindemuthianum* by dual culture technique:

Different antagonist bio-agents *viz. Trichoderma viride*, *Trichoderma harzianum*, *Pseudomonas fluorescens* and *Bacillus subtilis* were evaluated for their antagonistic activity against *C. lindemuthianum in vitro* by dual culture technique (Dennis and Webster, 1971). The tested bio agents and *C. lindemuthianum* were grown separately on potato dextrose agar (PDA) medium. The mycelial disc (5 mm diameter) of pathogen and fungal antagonists were placed on the same plate 6 cm away from each other. To test for antagonistic bacteria, a 5 mm of the mycelial disc of pathogen cultures were placed on one side of a Petri plate containing PDA medium. A loopful of bacteria was streaked 3 cm away from the disc of *C. lindemuthianum* on the same plate. Paired cultures were incubated at 27±2 °C. The plates inoculated only with test pathogen served as control. Four repetitions were maintained for each antagonist. The antagonistic fungal culture was maintained on PDA culture media and bacterial cultures were maintained on nutrient agar (NA) media. The assay for antagonism was performed on PDA media on Petri plates by the dual culture method. Inhibition zone were measured at 24 hours interval till the colony in the control plate covered with mycelium of pathogen. Per cent Growth Inhibition (PGI) were calculated by using the formula suggested by Vincent (1947).

$$PGI = \frac{C-T}{C} \times 100 \quad (1)$$

Where: -

PGI= Per cent growth inhibition

C= Colony diameter in control (mm)

T= Colony diameter in treatment (mm)

2.2 Efficacy of different organic inputs and phytoextracts against *C. lindemuthianum in vitro* and in pot condition:

Efficacy of different organic inputs and phytoextracts *viz. panchagavya*, *jivamrutha*, cow urine, vermiwash, neem leaf extract, ginger rhizome extract, garlic bulb extract, datura leaf extract at 5 and 10 per cent, respectively were tested *in vitro* by using poisoned food technique to know their inhibitory effect on the growth of *C. lindemuthianum*. Fresh and healthy, 100 g plant parts *i.e.* leaf, bulb or rhizome, respectively of each phytoextracts were collected, washed thoroughly with tap water and then with sterilized distilled water. Respective plant parts were crushed in mixer grinder by adding 100 ml sterilized distilled water to obtained 1:1 extracts separately. Each phyto-extracts thus obtained were centrifuged and filtered through double layered sterilized muslin cloth in conical flasks and plugged. 100 ml PDA were taken in 250 ml conical flasks, plugged and sterilized by autoclaving at 15 psi for 20 minutes. After cooling to about 45 °C temperatures, 5 and 10 ml of respective concentration were mixed thoroughly in the flask containing PDA individually. From the 100 ml PDA mixed with extracts, 20 ml poured aseptically into sterilized Petri plates and four plates per treatment were kept. The PDA Petri plate were inoculated with 5 mm mycelial disc cut from the periphery of the *C. lindemuthianum.* Culture were grown on PDA medium in the centre with the help of sterilized cork borer. The Petri plates containing PDA media without extract were inoculated with 5 mm mycelial disc cut from the periphery *C. lindemuthianum*. Culture grown on PDA medium were placed in the centre with the help of sterilized cork borer served as a control. The Petri plates were incubated at 27 ± 2°C temperature in an incubator for seven days. The statistical analysis was done using factorial complete randomized design (FCRD) with four repetitions. Observations regarding per cent disease intensity were recorded on the basis of percent area of leaf surface extension growth from all plants following 0-5 scales (0, No disease; 1, < 5 % leaf area affected; 2, 6 to 10 % leaf area affected; 3, 11 to 25 % leaf area affected; 4, 26 to 50 % leaf area affected; 5, > 50 % leaf area affected) given by (Sharma, 1983). The per cent disease intensity (PDI) were calculated by using following formula given by McKinney (1923). The per cent disease control (PDC) were calculated with the help of the following formula (Mathur *et al.*, 1971).

$$\text{Per cent Disease Intensity (PDI)} = \frac{\text{Sum of individual rating}}{\text{Total no.of samples examined} \times \text{Maximum disease rating scale}} \times 100 \quad (2)$$

$$\text{Per cent Disease Control (PDC)} = \frac{\text{PDI in control} - \text{PDI in treatment}}{\text{PDI in control}} \times 100 \quad (3)$$

III. RESULTS AND DISCUSSION

3.1 Antagonistic effect of different bio-agents against *C. lindemuthianum* by dual culture technique:

The results presented in Table 1 revealed that the significant difference in the growth inhibition of all the antagonist. Among the tested fungal and bacterial antagonist, the fungal antagonist found superior over bacterial antagonist. It was recorded that *Trichoderma viride* showed maximum growth inhibition (60.48%) which was statistically followed by *T. harzianum* (50.19%). In case of bacterial bio-agents *Pseudomonas fluorescens* (28.25%) was potential antagonists followed by *Bacillus subtills* (24.35%).

TABLE 1
EFFICACY OF DIFFERENT BIO-AGENTS AGAINST *C. LINDEMUTHIANUM*

Tr. No.	Bio-agents	Per cent growth inhibition
T_1	*Trichoderma viride*	51.05 (60.48)
T_2	*Trichoderma harzianum*	45.11 (50.19)
T_3	*Pseudomonas fluorescens*	32.11 (28.25)
T_4	*Bacillus subtills*	29.57 (24.35)
T_5	Control	4.05 (0.50)
Mean		32.38 (32.75)
S. Em. ±		0.41
C. D. @ 5%		1.27
C. V. %		2.09

These findings were close enough with the results of Padder *et al.* (2010) that evaluated three bioagents *viz.*, *Trichoderma viride, T. harzianum and Gliocladium virens* under *in vitro* conditions against *C. lindemuthianum* and found that all the three antagonistic were significantly inhibited the mycelial growth of pathogen, maximum being with *T. viride* (69.21%) followed by *T. harzianum* (64.20%). Rathava *et al.* (2017) found that, *T. viride* (68.88%), *T. harzianum* (67.03%) and *T. fasciculatum* (64.44%) significantly inhibited pathogen growth and were appeared as strong and potent antagonists of *C. lindemuthianum.*

3.2 Efficacy of different organic inputs and phytoextracts against *C. lindemuthianum in vitro*:

The results (Table 2) revealed that all the organic inputs and phytoextracts were showed inhibitory effect on growth of *C. lindemuthianum in vitro*. The highest mean growth inhibition of 60.99 per cent was recorded with panchagavya, followed by *Jivamrutha* (57.17%) and vermiwash (56.15%), whereas lowest in datura leaf extract (25.45%) followed by ginger rhizome extract (34.28%).

The inhibition of fungal growth was increase with increase in concentration in all the tested organic inputs and phytoextracts. At 5 % concentration highest mean growth inhibition of 39.64 per cent was recorded with *jivamrutha* which was statistically at par with vermiwash (38.72%) and neem leaf extract (38.67%), whereas lowest growth inhibition were recorded with datura leaf extract (12.95%). At 10 % concentration highest mean growth inhibition of 82.83 per cent was recorded with *panchagavya* which was followed by *jivamrutha* (73.81%) showed at par result with vermiwash (72.82%), whereas lowest growth inhibition were recorded with cow urine (37.7%).

These findings were close enough with the results of Hippe (1991) reported that the accumulation of lipid bodies, thickening of cell walls and undulations of plasmalemma of the cells caused by garlic extract (10%) were similar to those produced by some synthetic fungicides. Garlic extract resulted in serious damage of the mycelium of *R. solani*, *C. lindemuthianum*, and *F. solani* appeared fragmented under standard electron microscope. Sugha (2005) reported that panchagavya was found effective against *Colletotrichum capsici* (97.91%) at 10 per cent concentration. Chatak (2020) studied the effect of organic inputs against anthracnose of black gram caused by *C. truncatum* and found that *jivamrutha* and *beejamrutha* gave highest inhibition.

3.3 Efficacy of different organic inputs and phytoextracts against *C. lindemuthianum* in pot condition

The organic inputs *viz.*, *Panchgavya*, *jivamrutha* and vermiwash and botanicals *viz.* neem leaf extract and garlic bulb extract that found most effective at 10 % concentration during *in vitro* investigation were selected and evaluated against *C. lindemuthianum* of black gram variety T-9 under pot conditions.

TABLE 2
EFFICACY OF DIFFERENT ORGANIC INPUTS AND PHYTOEXTRACTS AGAINST *C. LINDEMUTHIANUM IN VITRO*

Tr.no.	Treatment	Per cent growth inhibition		
		Concentration (%)		Mean
		5.0	10.0	
T_1	*Panchagavya*	37.17 (36.5)	65.52 (82.83)	51.35 (60.99)
T_2	*Jivamrutha*	39.02 (39.64)	59.22 (73.81)	49.12 (57.17)
T_3	Cow urine	34.53 (32.13)	37.88 (37.7)	36.21 (34.9)
T_4	Vermiwash	38.48 (38.72)	58.58 (72.82)	48.53 (56.15)
T_5	Neem leaf extract	38.45 (38.67)	46.86 (53.24)	42.65 (45.9)
T_6	Ginger rhizome extract	23.37 (15.73)	48.30 (55.75)	35.84 (34.28)
T_7	Garlic bulb extract	31.22 (26.87)	42.08 (44.91)	36.65 (35.63)
T_8	Datura leaf extract	21.09 (12.95)	39.51 (40.48)	30.3 (25.45)
T_9	Control (Water spray)	4.05 (0.5)	4.05 (0.5)	4.05 (0.5)
Mean		29.71 (26.86)	44.67 (51.34)	-
S. Em. ±		**Treatment**	**Concentration**	**Treatment × Concentration**
		0.29	0.15	**0.41**
C. D. @ 5%		0.82	0.41	**1.16**
C. V. %		**1.98**		

The pooled over sprays values (Table 3) revealed that vermiwash @ 10 % gave highest per cent disease control (57.20%) followed by Garlic bulb extract @ 10% (51.19%) and *Panchagavya* @10% (43.82%). The lowest per cent disease control were observed in *Jivamrutha* @ 10 % (35.75%) followed by Neem leaf extract @ 10% (41.68). These findings were close enough with the results of Gurjar *et al*. (2021) concluded that the solely application of Garlic 15% and Vermiwash 15% showed (36.29) disease severity with 43.67% disease control and (39.25) disease severity with 39.08% disease control, respectively.

TABLE 3
EFFICACY OF DIFFERENT ORGANIC INPUTS AND PHYTOEXTRACTS AGAINST *C. LINDEMUTHIANUM* IN POT CONDITION

Tr.no.	Treatments	Con. (%)	After 1st spray		After 2nd spray		After 3rd spray		Pooled PDC
			PDI	PDC	PDI	PDC	PDI	PDC	
T_1	*Panchagavya*	10.0	26.18 (19.47)	40.83 (42.75)	28.06 (22.13)	**41.57 (44.03)**	30.31 (25.47)	42.11 (44.96)	41.45 (43.82)
T_2	*Jivamrutha*	10.0	28.63 (22.96)	35.01 (32.92)	30.31 (25.47)	**36.30 (35.05)**	31.93 (27.97)	38.84 (39.33)	36.72 (35.75)
T_3	Vermiwash	10.0	21.82 (13.82)	47.27 (53.96)	24.42 (17.09)	**49.10 (57.13)**	27.45 (21.25)	51.04 (60.46)	49.14 (57.20)
T_4	Neem leaf extract	10.0	26.91 (20.48)	39.51 (40.48)	28.63 (22.96)	**40.12 (41.52)**	30.85 (26.30)	41.00 (43.04)	40.21 (41.68)
T_5	Garlic bulb extract	10.0	24.47 (17.16)	45.27 (50.47)	25.65 (18.74)	**46.58 (52.76)**	28.61 (22.93)	45.18 (53.31)	45.68 (51.19)
T_6	Control	-	35.55 (33.8)	-	38.53 (38.8)	**-**	42.4 (45.47)	-	-
Mean			27.26 (21.28)	36.23 (34.93)	29.27 (23.9)	**36.57 (35.5)**	31.92 (27.96)	36.69 (35.7)	42.64 (45.93)
S. Em. ±			0.78	1.89	0.81	**1.55**	0.79	1.53	1.01
C. D. @ 5%			2.33	5.63	2.42	**4.60**	2.34	4.54	2.85
C. V. %			5.75	10.45	5.56	**8.47**	4.94	8.43	9.13

IV. CONCLUSION

The present investigation demonstrated the potential of bio-agents, organic inputs, and phytoextracts as effective non-chemical alternatives for the management of anthracnose disease in black gram caused by *Colletotrichum lindemuthianum*. Among the evaluated antagonists, *Trichoderma viride* proved most effective, showing 60.48% growth inhibition, followed by *T. harzianum* (50.19%), while bacterial bio-agents exhibited comparatively lower efficacy. Similarly, among organic inputs and phytoextracts, *panchagavya* recorded the highest inhibition (60.99%) *in vitro*, followed by *jivamrutha* (57.17%) and vermiwash (56.15%). The results further indicated that the inhibitory effect increased with higher concentrations of the treatments.

Under pot conditions, vermiwash at 10% concentration provided the highest disease control (57.20%), followed by garlic bulb extract (51.19%). These findings highlight the scope of utilizing eco-friendly, sustainable, and easily available bio-agents and organic formulations in integrated disease management strategies for black gram cultivation. The study concludes that *T. viride*, panchagavya, vermiwash, and garlic bulb extract can serve as promising alternatives to chemical fungicides, reducing dependence on synthetic inputs while contributing to sustainable agriculture. Further field validation is recommended to confirm their efficacy under diverse agro-climatic conditions.

CONFLICT OF INTEREST

The authors, affiliated with declare no conflicts of interest

REFERENCES

[1] Anonymous (2020). Black gram-Commodities Control. Retrieved from http://www.commoditiescontrol.com

[2] Chatak S. 2020. Integrated disease management of urdbean anthracnose caused by *Colletotrichum truncatum* (M. Sc. (Agri.) Thesis, Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishvavidyalaya, Palampur, India). Retrieved from https://krishikosh.egranth.ac.in/handle/1/5810154324

[3] Deeksha J and Tripathi HS. 2002. Cultural, biological and chemical control of anthracnose of urdbean. *Journal of Mycology and Plant Pathology*. **32**(1): 52-55.

[4] Dennis C and Webster J. 1971. Antagonistic properties of species-groups of Trichoderma: I. Production of non-volatile antibiotics. *Transactions of the British Mycological Society*. **57**(1): 25-IN3.

[5] Gopalan C, Shastri BV and Balasubramaniam SC. 1971. Nutritive value of Indian foods. National Institute of Nutrition, Indian Council of Medical Research (ICMR), Hyderabad.

[6] Gurjar AK, Bunker RN and Sharma AK. 2021. Efficacy of fungicides, botanicals and organic amendments to suppress the anthracnose of soybean caused by *Colletotrichum truncatum* (Schw.) Andrus and Moore. *The Pharma Innovation Journal.* **10**(9): 1633-1638.

[7] Hippe S. 1991. Influence of fungicides on fungal fine structure; electron microscopy of plant pathogens. Mendgee, K. and Lesemann, D. E. (Ed.). Springer Verlag. Berlin. pp. 317-331.

[8] Kulkarni SA. 2009. Epidemiology and integrated management of anthracnose of green gram (Doctoral thesis, UAS, Dharwad, Karnataka). Retrieved from http://krishikosh.egranth.ac.in/handle/1/69455.

[9] Laxman R. 2006. Studies on leaf spot of green gram caused by *Colletotrichum truncatum* (Schwein.) Andrus & Moore. Master's thesis, UAS, Dharwad, Karnataka. Retrieved from http://krishikosh.egranth.ac.in/handle/1/97608.

[10] Mathur RS, Singh BK, Nagarkoti MS. 1971. Control of early blight of potato with fungicides. *Indian Phytopathology*. **24**:58-62.

[11] Mc kinney HH. 1923. Influence of soil temperature and moisture on infection of wheat seedlings by *helminthosporium sativam*. *Indian Journal of Agricultural Research*. **26**: 195-217

[12] Padder BA, Sharma PN, Renu K, Anju P and Sharma OP. 2010. Evaluation of bio-agents and biopesticides against *Colletotrichum lindemuthianum* and its integrated management in Common Bean. *Notulae Scientia Biologicae.* **2**(3): 72-76.

[13] Parashar. 2006. Post-harvest profile of black gram. MRPC-71, Ministry of agriculture, Directorate of marketing and inspection. Retrieved from http://agmarknet.nic.in/preface-blackgram.

[14] Piper CV and Morse WJ. 1914. Five oriental species of beans. USDA Bulletin, No. 119.

[15] Rathava A, Pathak DM, Vahunia B and Patel NY. 2017. Efficacy of bio-agents against *Colletotrichum lindemuthianum* causing anthracnose of cowpea. *Trends in Biosciences.* **10**(23): 4626-4628.

[16] Saxena RM and Sinha S. 1977. Seed borne infection of *Vigna mung*o in Uttar Pradesh. *Indian Phytopathology*. **30**: 582-583.

[17] Sharma A and Verma KS. 2007. *In vitro* cross pathogenicity and management of *Colletotrichum gloeosporioides* causing anthracnose of mango. *Annals of Plant Protection Sciences.* **15**(1): 186-188.

[18] Sharma HLA. 1983. Technique for identifying and rating resistance to foliar diseases of sorghum under field conditions. *Proceedings Indian Academy of Science*. **42**(2): 278-283.

[19] Sugha SK. 2005. Antifungal potential of panchagavya. *Plant Disease Research*. **20**(2): 156-158.

[20] Vavilov NI. 1926. Studies on the origin of cultivated plants. *Chronica Botanica*. **13:** 1949- 1950.

[21] Vincent JM. 1947. Distortion of fungal hyphae in the presence of certain inhibitors. *Nature*, **159**(4051), 850.

A Qualitative Estimation of Secondary Metabolites in Selected Leafy Vegetables Cultivated in Hydroponic System – Part I

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Abstract— *Leafy vegetables are important in medicine and are easily accessible, making them the most affordable source of treatment in the primary healthcare system for poor communities. Phytochemicals are plant components with specific bioactivities in animal biochemistry and metabolism. They are being extensively studied for their potential to provide health benefits. It is crucial to establish a scientific rationale to support their use in foods as potential nutritionally active components. Some of the significant phytochemicals with a variety of biological functions include alkaloids, flavonoids, phenolics, tannins, terpenoids, steroids, glycosides, and terpenes. The current investigation evaluates the phytochemical profiles of a sample of 8 leafy vegetable species cultivated in both soil-based and hydroponic growing environments. The study found that some species in both cultivation methods contain phenolics, flavonoids, alkaloids, and terpenoids. The importance of specific plant species is examined in relation to their role in ethnomedicine, and these results will be useful for further comparative studies of phytochemistry in beds and for subsequent studies on hydroponic cultivation.*

Keywords— Leafy vegetables, Phytochemicals, Secondary metabolites, Hydroponic, Ethnomedicine, Beneficial.

I. INTRODUCTION

Vegetables are an important component of daily meals because they are vital for supplying nutrients, preventing disease, and promoting general health. Leafy vegetables, such as amaranth and spinach, play a vital role in human nutrition. They are a rich source of vitamins, minerals, and phytochemicals, all of which are essential for maintaining good health. Natural plant merchandise was used for medicinal programs on the grounds that historic times. However, with advancements in various scientific fields, herbal medicines have been developed. Investigating regional flora as potential sources of crude extracts or chemicals with therapeutic qualities is currently gaining traction. "Medicinal plants have been studied to determine their potential to offer safe, affordable, and effective remedies for various diseases. This has led to an increased interest in creating natural remedies as alternatives to commonly used synthetic drugs. Phytochemicals are bioactive substances produced by plants metabolically, which have protective and detoxifying properties [2][23]. They are non-nutritive components that shield plants from environmental stresses and are responsible for various physiological activities. Leafy vegetables are an excellent source of beneficial microflora. Since they are relatively non-nutritive, they are an effective method of shielding probiotics from bile salt and stomach acid damage. Antimicrobial plants contain diverse bioactive secondary metabolites, such as alkaloids, terpenes, tannins, saponins, and flavonoids. Flavonoids and Alkaloids have antibacterial, antiviral, and anticancer properties. Other secondary metabolites include phenolic and polyphenolic compounds. Plant-derived chemicals have been proven to be effective in controlling diseases, and importantly, they have no adverse impacts on humans or the environment".

Phytochemicals are extracted from plant material using methods like maceration, percolation, infusion, hot continuous extraction (Soxhlet extraction), etc. Eco-friendly techniques like Ultrasound-Assisted Extraction, Microwave-Assisted Extraction, etc., are also used. The extraction procedure used a variety of solvents, including water, ethanol, methanol, acetone, ether, benzene, chloroform, etc [16][33]. The phytochemical screening of eight distinct leafy vegetable species is compared in this study, including *Raphanus sativus L.* (Mooli bhaji), *Chorchorus olitorius L.* (Chech bhaji), *Lathyrus sativus L.* (Lakhdi bhaji), *Carthamus tinctorius L*. (Kusum bhaji), *Amaranthus tricolor L*. (Lal bhaji), *Mentha piperital L*. (Peppermint), *Ipomea aquatica F*. (Karmata bhaji), *Trigonella foenum-graecum L.* (Methi bhaji). These vegetables were grown in both soil and hydroponic systems.

II. MATERIAL AND METHODS

Eight different species of leafy vegetables, namely *Raphanus sativus L*. (Mooli bhaji), *Chorchorus olitorius L.* (Chech bhaji), *Lathyrus sativus L*. (Lakhdi bhaji), *Carthamus tinctorius L*. (Kusum bhaji), *Amaranthus tricolor L*. (Lalbhaji), *Mentha piperital L*. (Peppermint), *Ipomea aquatica F*. (Karmata bhaji), *Trigonella foenum-graecum* L. (Methi bhaji) were selected for this study. The samples were cultivated in the backyard of the Life Science department in Pandit Ravishankar Shukla University, Raipur, Chhattisgarh (India) from January to April the year 2023-2024. In this experiment, we took fresh mature leaves from plants grown in soil and plants grown hydroponically. We thoroughly washed the leaves, sliced them into small pieces, and then dried them in the shade at a temperature of 25 ± 2 ºC for about 7 days. An appropriate grinder was then used to grind the dried plant fragments into a coarse powder. The powder was then stored in an airtight container in a cold, dark, and dry environment until analysis began. The plant leaf samples were extracted using methanol.100 cc of methanol was added to a flask containing 10 g of each powdered plant material, and the flask was left to stand for 48 to 72 hours. The mixture was filtered using Whatman filter paper No. 1. The resulting extracts were labeled as methanol extract and stored in sealed bottles at 5°C for future use [9].

Fresh mature leaves of the sample	Fresh Sample Cut into small pieces and dried in the shade at a temperature of 25 ± 2ºC	Dried plants processed into a coarse powder	Methanol Extract of Dried Sample

FIGURE 1. Showing the process of making Methanol extract using Dry Sample

2.1 Phytochemical Screening:

- **Test for alkaloid (Wagner's test):** Two millilitres of test sample filtrate were mixed with one or two drops of Wagner's reagent (iodine in potassium iodide) along the sides of the test tube in order to perform the alkaloid-detection test. The appearance of reddish-brown precipitates indicates the presence of an alkaloid [29].
- **Test for Flavonoids (Ferric chloride test):** Two millilitres of the filtrate from the test sample were mixed with a few drops of a 10% ferric chloride solution. The presence of flavonoids in the sample is indicated by a green precipitate at the bottom of the test tube [9].
- **Test for Phenolics (Lead acetate test):** Five millilitres of the filtrate from the test sample were mixed with three millilitres of a 10% lead acetate solution. White precipitate indicates the presence of the phenolic component in the test sample [34].
- **Test for Tannins (10% NaOH test):** In 0.4 millilitres filtrate of the test sample, 4 millilitres of 10% sodium hydroxide solution was added and shaken well. The emulsion's formation indicates that the test sample contains tannins [34].
- **Test for Terpenoids (Salkowski's test):** After adding two millilitres of chloroform to five millilitres of the test sample filtrate, the mixture is evaporated on a water bath. The liquid is then brought to a boil on a water bath with three millilitres of pure sulfuric acid added. There are terpenoids present if a grey-coloured solution is formed [9].

- **Test for Phytosterols (Sulphuric acid test):** A few drops of concentrated H_2SO_4(sulphuric acid) were added to three millilitres of filtrate. shaken thoroughly and left to stand. The red colour at the lower layer indicates the presence of phytosterol in the sample [9].

III. RESULT AND DISCUSSION

TABLE 1
SHOWING ASSESSMENT OF PHYTOCHEMICALS IN THE LEAF EXTRACT OF LEAFY VEGETABLES CULTIVATED IN SOIL AND HYDROPONIC

S.No.	Plant Species	Parameters											
		Alkaloids		Flavonoids		Phenolics		Tannins		Terpenoids		Phytosterols	
		SCP	HCP	SCP	HCP	SCP	HCP	SCP	HCP	SCP	HCP	SCP	HCP
1	*Raphanus sativus L*	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve
2	*Chorchorus olitorius L.*	+ve	+ve	+ve	+ve	+ve	+ve	-ve	-ve	+ve	+ve	+ve	+ve
3	*Lathyrus sativus L.*	+ve	+ve	+ve	+ve	+ve	+ve	-ve	-ve	+ve	+ve	-ve	-ve
4	*Carthamus tinctorius L.*	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	-ve	-ve	-ve	-ve
5	*Amaranthus tricolor L.*	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve
6	*Mentha arvensis*	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	-ve	-ve	+ve	+ve
7	*Ipomea aquatica F.*	+ve	+ve	+ve	+ve	+ve	+ve	-ve	-ve	+ve	+ve	-ve	-ve
8	*Trigonella foenum-graecum L.*	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve

+ve = Presence; SCP: Soil Cultivated Plant -ve = Absent; HCP: Hydroponic Cultivated Plant

Alkaloids

SCP | **HCP**

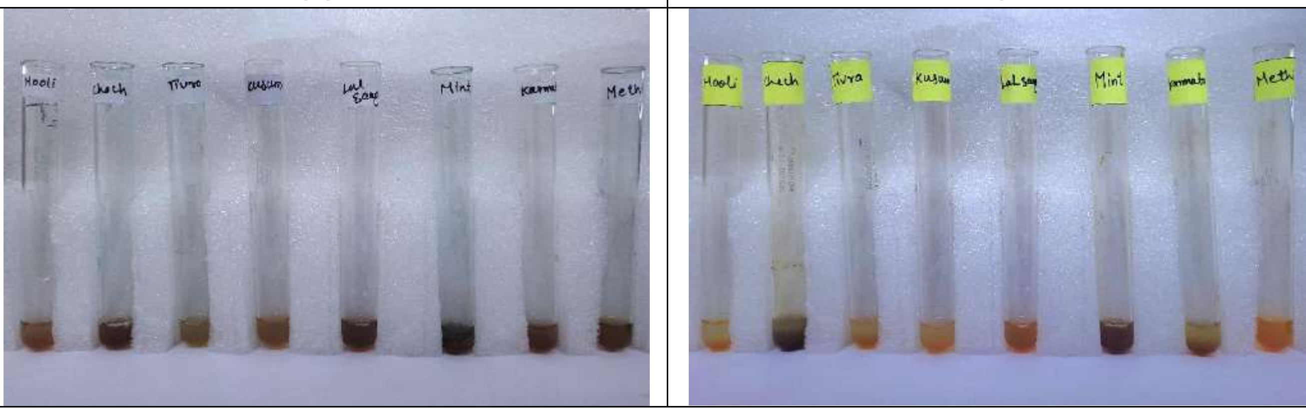


FIGURE 2. Showing the Qualitative Test of Alkaloids in SCP and HCP

Flavonoids

SCP | **HCP**

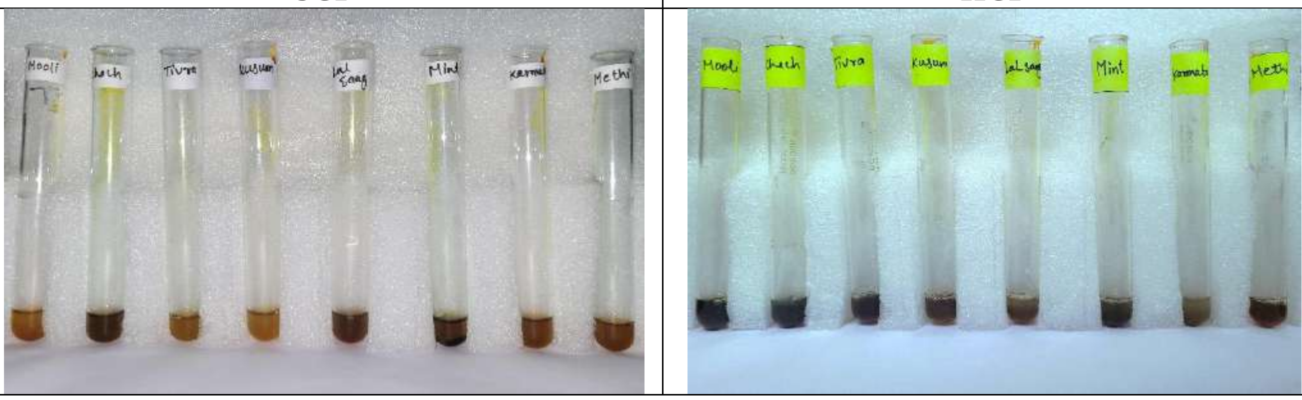


FIGURE 3. Showing the Qualitative Test of Flavonoids in SCP and HCP

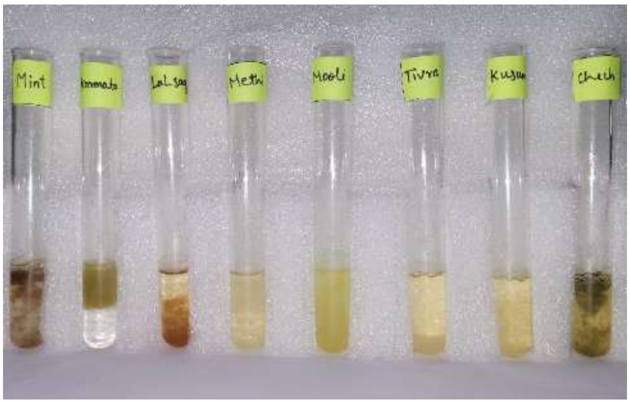
Phenolics	
SCP	**HCP**
	

FIGURE 4. Showing the Qualitative Test of Phenolics in SCP and HCP

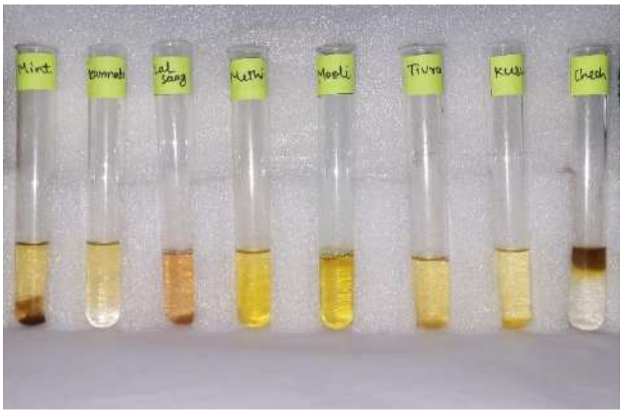
Tannins	
SCP	**HCP**
	

FIGURE 5. Showing the Qualitative Test of Tannins in SCP and HCP

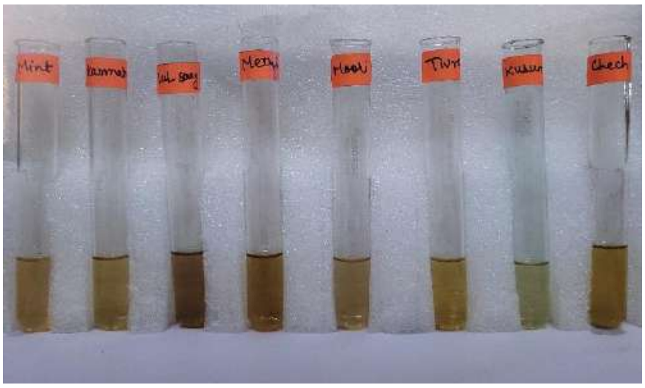
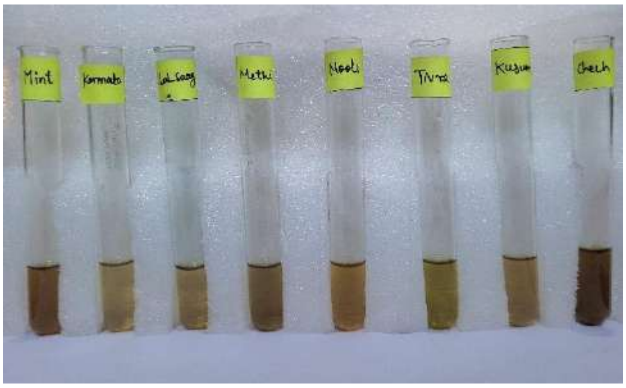
Terpenoids	
SCP	**HCP**
	

FIGURE 6. Showing the Qualitative Test of Terpenoids in SCP and HCP

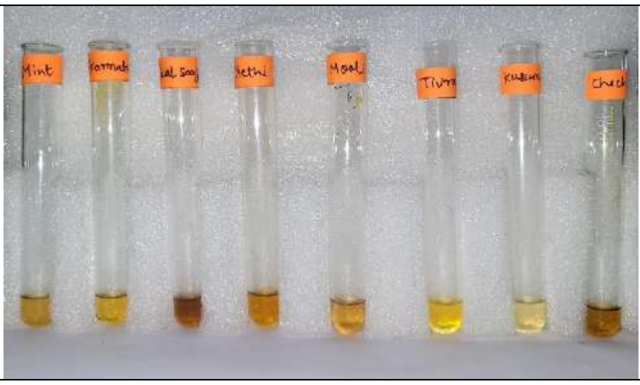
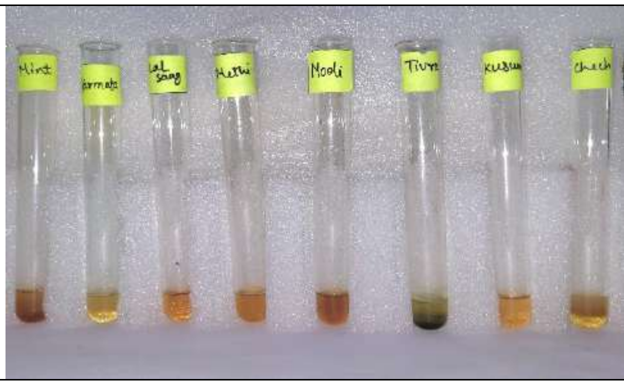
Phytosterols	
SCP	**HCP**
	

FIGURE 7. Showing the Qualitative Test of Phytosterols in SCP and HCP

The results of eight leafy vegetable species cultivated in soil and hydroponic systems are reported in Table 1. Study reveals that the presence and absence of secondary metabolites are similar in both soil-cultivated and hydroponically cultivated plants. All plant species had tannins, except *Lathyrus sativus L., Ipomea aquatica F.,* and *Chorchorus olitorius L.* Every plant species has terpenoids, except *Mentha arvensis,* and *Carthamus tinctorius L.* Phytosterols were found in all plant species except *Lathyrus sativus L., Carthamus tinctorius L., Ipomea aquatica F.*

- ***Raphanus sativus L.*** has compounds like alkaloids, flavonoids, phenols, tannins, terpenoids, and phytosterols, whether it's grown in soil or using hydroponic methods.
- ***Chorchorus olitorius L.*** has alkaloids, flavonoids, phenolics, terpenoids, and phytosterols in both soil-grown and hydroponic plants, but it does not contain tannins.
- ***Lathyrus Sativus L.*** contains alkaloids, flavonoids, phenolics, and terpenoids in both soil and hydroponic cultivation, except for tannins and phytosterols.
- ***Carthamus tinctorius L.*** has alkaloids, flavonoids, phenolics, and Tannins in both soil-grown and hydroponically grown plants, but it does not contain terpenoids and phytosterols.
- ***Amaranthus tricolor L.*** contains alkaloids, flavonoids, phenolics, tannins, terpenoids, and phytosterols in both soil and hydroponic cultivation.
- ***Mentha piperita L.*** contains various chemical compounds such as alkaloids, flavonoids, phenolics, tannins, and phytosterols in both soil-grown and hydroponic systems, except terpenoids.
- ***Ipomea aquatica F.*** contains alkaloids, flavonoids, phenolics, and terpenoids in both soil and hydroponic cultivation, except for tannins and phytosterols
- ***Trigonella foenum-graecum L.*** contains a variety of bioactive compounds such as alkaloids, flavonoids, phenolic substances, terpenoids, and phytosterols in both soil-grown and hydroponic systems, except tannins.

IV. CONCLUSION

The research compares the presence of plant chemicals in eight types of leafy vegetables grown in soil and in water-based growing systems. It evaluates the qualitative estimation of Secondary Metabolites in various species, showing similar results for both soil and hydroponically cultivated plants. This shows how hydroponics can offer better nutrient buildup and higher crop production. Hydroponic plants often have a higher level of advantageous compounds compared to plants cultivated in soil. However, it is important to consider the associated costs and the efforts required for management to achieve positive results. This analysis emphasizes the potential of hydroponics as a viable alternative to traditional soil farming, particularly in areas facing land and water scarcity.

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REFERENCES

[1] B. Neeharika, K. Patel, J. Suneetha, and B. A. Kumari, "Blanched bathua leaves: Influence on phytochemical and antioxidant properties," *Int. J. Conserv. Sci.*, vol. 7, pp. 793–799, 2019.

[2] C. S. Ezeonu and C. M. Ejikeme, "Qualitative and quantitative determination of phytochemical contents of indigenous Nigerian softwoods," *New J. Sci.,* pp. 1–9, 2016.

[3] D. Sinha, S. Mukherjee, and S. Chowdhury, "Methods of extraction of phytochemicals," in *Phytochemicals*, ch. 10, 2022. doi: 10.4018/978-1-6684-7337-5.ch010.

[4] E. De Almeida Melo, J. Mancini Filho, and N. B. Guerra, "Characterization of antioxidant compounds in aqueous coriander extract (Coriandrum sativum L.)," *LWT-Food Sci. Technol.*, vol. 38, no. 1, pp. 15–19, 2005.

[5] F. Beddou et al., "Potential assessment of Rumex vesicarius L. as a source of natural antioxidants and bioactive compounds," *J. Food Sci. Technol.*, vol. 52, pp. 3549–3560, 2015.

[6] H. Meena, B. Ballabh, S. Arya, and M. Bala, "Evaluation of phytochemicals, antioxidant property, and effects of Cichorium intybus cultivated at foothill area of Uttarakhand on hyperglycemic rats," *Int. J. Compr. Adv. Pharmacol.*, vol. 7, no. 1, pp. 54–64, 2022.

[7] H. T. Adejoke, H. Louis, O. O. Amusan, and G. Apebende, "A review on classes, extraction, purification and pharmaceutical importance of plant alkaloid," *J. Med. Chem. Sci.*, vol. 2, no. 4, pp. 130–139, 2019.

[8] J. Parekh and S. Chanda, "Phytochemicals screening of some plants from western region of India," *Plant Arch.*, vol. 8, pp. 657–662, 2008.

[9] J. R. Shaikh and M. Patil, "Qualitative tests for preliminary phytochemical screening: An overview," *Int. J. Chem. Stud.*, vol. 8, no. 2, pp. 603–608, 2020.

[10] K. Patel and M. Vakilwala, "Phytochemical study and bioactivity of solvent extracts on Coriandrum sativum," *Int. J. Adv. Res. Biol. Sci.*, vol. 3, no. 5, pp. 193–199, 2016.

[11] K. Patil and A. P. Jain, "Extraction, qualitative and quantitative determination of secondary metabolites of Corchorus olitorius," *Chem. Reagents*, 2017.

[12] Khanal, "Phytochemical and antibacterial analysis of Mentha piperita (Peppermint)," Doctoral dissertation, 2020.

[13] M. G. Rasul, "Conventional extraction methods use in medicinal plants, their advantages and disadvantages," *Int. J. Basic Sci. Appl. Comput.*, vol. 2, no. 6, pp. 10–14, 2018.

[14] M. Madhu et al., "Quantitative phytochemical analysis of selected medicinal plant species by using various organic solvents," *J. Pharmacogn. Phytochem.*, vol. 5, no. 2, pp. 25–29, 2016.

[15] M. Manvar and T. Desai, "Phytochemical and pharmacological profile of Ipomoea aquatica," *Indian J. Med. Sci.,* vol. 67, no. 3–4, p. 49, 2013.

[16] N. N. Azwinda, "A review on the extraction method used in medicinal plants, principle, strength and limitation," *Medicinal and Aromatic Plants*, vol. 4, no. 3, pp. 1–6, 2015.

[17] N. Sharma, V. Kumar, and N. Gupta, "Phytochemical analysis, antimicrobial and antioxidant activity of methanolic extract of Cuscuta reflexa stem and its fractions," *Vegetos*, vol. 34, pp. 876–881, 2021.

[18] O. S. Kumari, N. B. Rao, and R. G. Gajula, "Phytochemical analysis and anti-microbial activity of Trigonella foenum-graecum (Methi seeds)," Diabetes, vol. 1, no. 19, p. 4, 2016.

[19] P. Diwan, R. K. Naik, and A. Gautam, "Studies on the status and opportunity of leafy vegetable crop harvesting in Chhattisgarh," *Biol. Forum – Int. J.,* vol. 13, no. 4, pp. 837–841, 2021.

[20] R. Abubakar and M. Haque, "Preparation of medicinal plants: Basic extraction and fractionation procedures for experimental purposes," *J. Pharm. Bioallied Sci.*, vol. 12, no. 1, pp. 1–10, 2020. doi: 10.4103/jpbs.JPBS_175_19.

[21] R. N. S. Yadav and M. Agarwala, "Phytochemical analysis of some medicinal plants," *J. Phytol.*, vol. 3, no. 12, 2011.

[22] R. Routrayi, M. Kar, and R. K. Sahu, "Evaluation of antioxidant potential in selected leafy vegetables of Odisha, India," *Int. J. Pharm. Pharm. Sci.*, vol. 5, pp. 232–235, 2013.

[23] R. Sheel, K. Nisha, and J. Kumar, "Preliminary phytochemical screening of methanolic extract of Clerodendron infortunatum," *IOSR J. Appl. Chem.*, vol. 7, no. 1, pp. 10–13, 2014.

[24] S. A. Ahmed, S. Hanif, and T. Iftkhar, "Phytochemical profiling with antioxidant and antimicrobial screening of Amaranthus viridis L. leaf and seed extracts," *Open J. Med. Microbiol.*, vol. 3, no. 3, pp. 164–171, 2013.

[25] S. A. Audu, I. Mohammad, and H. A. Kaita, "Phytochemical screening of the leaves of Lophira lanceolata (Ochanaceae)," *Life Sci. J.*, vol. 4, no. 4, pp. 75–79, 2007.

[26] S. Alok et al., "Plant profile, phytochemistry and pharmacology of Asparagus racemosus (Shatavari): A review," *Asian Pac. J. Trop.* Dis., vol. 3, no. 3, pp. 242–251, 2013. doi: 10.1016/s2222-1808(13)60049-3.

[27] S. Badyal, H. Singh, A. K. Yadav, S. Sharma, and I. Bhushan, "Plant secondary metabolites and their uses," *Plant Arch.*, vol. 20, no. 2, pp. 3336–3340, 2020.

[28] S. Dayani and M. R. Sabzalian, “Production of secondary metabolites in medicinal plants through hydroponic systems,” in Controlled Environmental Agriculture, *Nova Science*, Inc., New York, pp. 33–53, 2017.

[29] S. Kaliyaperumal and M. Radhika, “Study of phytochemical analysis and antioxidant activity of Spinach oleracea L. plant leaves,” *Pharma Innov. J*., vol. 9, no. 7, pp. 1–4, 2020.

[30] S. Nathenial et al., “Phytochemical study of acetone solvent extract of Coriandrum sativum,” *J. Pharmacogn. Phytochem.,* vol. 8, no. 6, pp. 136–140, 2019.

[31] S. S. Mulay, “Pharmacognostic account and phytochemical studies of Hibiscus sabdariffa Linn,” *World J. Pharm. Res*., vol. 7, no. 14, pp. 978–985, 2018.

[32] Singh and Ram Avtar Sharma, *Secondary Metabolites of Medicinal Plants*. John Wiley & Sons, 2020.

[33] T. Dhanani, S. Shah, N. A. Gajbhiye, and S. Kumar, “Effect of extraction methods on yield, phytochemical constituents and antioxidant activity of Withania somnifera,” *Arabian Journal of Chemistry,* vol. 10, pp. 1193–1199, 2017.

[34] V. Singh and R. Kumar, “Study of phytochemical analysis and antioxidant activity of Allium sativum of Bundelkhand region,” *Int. J. Life-Sci. Sci. Res*., vol. 3, no. 6, pp. 1451–1458, 2017.

[35] V. Tamrakar, D. Arora, and C. Arora, “Phytochemical screening of leafy vegetables of Chhattisgarh state,” *Ann. Hortic*., vol. 10, no. 2, pp. 202–206, 2017.

Spatio-Temporal Analysis and Forecasting of Soil Moisture in North Gujarat using NASA SMAP Data and Google Earth Engine: An Integrated Approach for Agricultural Water Management

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Abstract— *Soil moisture plays a critical role in agricultural productivity, hydrological processes, and climate interactions, particularly in semi-arid regions. This study investigates soil moisture variability in North Gujarat by integrating NASA's Soil Moisture Active Passive (SMAP) datasets with Google Earth Engine (GEE) capabilities. A modular Python-based analytical pipeline was developed for data acquisition, preprocessing, correlation analysis, anomaly detection, trend estimation, and time-series forecasting using SARIMA and ARIMA models. The SARIMA model, incorporating precipitation as an exogenous factor, achieved an RMSE of 0.0781 m³/m³ and an MAE of 0.0615 m³/m³ for surface moisture prediction. The system also integrates an irrigation decision-support logic that determines optimal ON/OFF irrigation sequences based on real-time and forecasted moisture levels. Results reveal stable soil moisture conditions with no anomalies in the last 30 days, enabling improved irrigation scheduling for water-constrained agro-systems in North Gujarat.*

Keywords— Soil Moisture, SARIMA, ARIMA, NASA SMAP, Google Earth Engine, Remote Sensing, Irrigation Decision Support.

I. INTRODUCTION

The interaction between soil moisture and atmospheric processes significantly influences climate variability, hydrological cycles, and agricultural productivity. Semi-arid regions such as North Gujarat face persistent water stress, making soil moisture monitoring essential for sustainable farming and food security. The development of satellite-based sensing technologies and cloud-computing platforms, such as NASA's SMAP mission and Google Earth Engine (GEE), provides unprecedented capabilities for continuous, high-resolution soil moisture monitoring.

The relationship between soil moisture and the interaction between soil and atmosphere has been extensively investigated by Seneviratne et al. (2010) providing a comprehensive picture of how soil moisture influences climate variability and extremes[1]. Their research shows that soil moisture acts as a key mediator in water and energy cycles, affecting in particular temperature and precipitation patterns by evapotranspiration. This basic understanding underpins the importance of monitoring soil moisture variations in order to predict climate change and agricultural performance in water-scarce environments.

In semi-arid regions, soil moisture dynamics are characterized by high temporal and spatial variability, which significantly impacts agricultural productivity and water resource management. Porporato et al. (2004) developed a stochastic framework for understanding soil moisture dynamics in water-limited ecosystems, revealing how intermittent precipitation events interact with soil properties and vegetation to create complex moisture patterns [2]. Their mathematical modelling approach provides insight into the probabilistic nature of the availability of moisture in the soil, which is particularly important in semi-arid agricultural systems where crop performance is highly dependent on the ability of the soil to store water and the timing of rainfall events.

The use of remote sensing techniques has revolutionised the ability to monitor soil moisture, allowing for large-scale assessments of wetland conditions in a variety of landscapes. Dorigo and colleagues. (2017) presented the ESA CCI Soil moisture dataset, which provides a global long-term record of soil moisture from several satellite sensors[3]. This comprehensive dataset has proven invaluable for understanding regional soil moisture trends and their relationships with climate variability, offering crucial data for semi-arid regions where ground-based monitoring networks are often sparse or lacking.

Agro-systems in semi-arid regions face unique challenges in managing soil moisture, especially in the light of climate change and increasing weather variability. RockStrom et al. (2010) looked at water productivity in rain-fed agriculture and highlighted the crucial role of soil moisture management techniques in increasing crop yields and food security in dry-land farming systems[4]. Their analysis highlights various water harvesting and soil management practices that can improve moisture retention and utilization efficiency, providing practical solutions for farmers in regions like North Gujarat where rainfall reliability is a constant concern.

The Indian subcontinent, including regions like North Gujarat, presents specific challenges and opportunities for soil moisture research due to its monsoonal climate patterns and diverse agricultural practices. Singh et al. (2014) investigated soil moisture variability across different agro-climatic zones of India using satellite-based observations, revealing significant regional differences in moisture patterns and their correlations with monsoon intensity[5]. Their findings show the complex interaction of topography, soil characteristics and climatic factors in determining moisture availability and provide valuable insights for planning agriculture and managing water resources in semi-arid regions of India.

Recent advances in machine learning and data assimilation techniques have enhanced our ability to predict and model soil moisture dynamics in complex semi-arid environments. Feng and colleagues (2017) developed machine learning approaches to improve soil moisture forecasting using multiple satellite data sets and meteorological variables. [6]. Their research demonstrates how advanced computational methods can integrate diverse data sources to provide more accurate soil moisture estimates, which is particularly valuable for agricultural decision-making and drought monitoring in semi-arid regions where traditional monitoring approaches may be inadequate.

This study combines SMAP datasets with GEE-based spatial analysis and time-series forecasting techniques to address three major challenges: 1) Reliable monitoring of spatio-temporal changes in soil moisture. 2) Accurate short-term forecasting using rainfall data as an influencing parameter. 3)Integration of forecast results into an automated irrigation decision-support framework.

II. LITERATURE REVIEW

Literature on soil moisture monitoring and forecasting consistently underscores its fundamental role in regulating land–atmosphere interactions, controlling hydrological processes, and sustaining agricultural productivity, particularly in water-limited environments.

2.1 Remote Sensing of Soil Moisture:

Over the last thirty years, the field of satellite-based soil moisture estimation has made remarkable progress, especially with the advent of passive microwave sensors, which have emerged as the technology of choice for global monitoring initiatives (Jackson, 1993). The “Soil Moisture Active and Passive” (SMAP) and “Soil Moisture and Ocean Salinity” (SMOS) missions serve as prime examples of this advancement, contributing significantly to our comprehension of the exchanges of energy between “the land surface and the atmosphere”, as well as the essential role that “soil moisture content” (SMC) plays in hydrometeorological dynamics (Edokossi et al., 2020). Conventional measurement approaches often face limitations due to their high costs and logistical difficulties when applied over large areas, making satellite monitoring increasingly crucial for precise tracking of SMC[7].

Recently, enhancements in Global Navigation Satellite Systems Reflectometry (GNSSR) have presented a compelling alternative, boasting benefits such as worldwide coverage, affordability, and the ability to function in all weather conditions (Yin et al., 2019). The SOMOSTA experiment demonstrated the efficacy of GNSSR in relation to passive L-band microwave radiometers, revealing strong correlation coefficients between the two methods and confirming the reliability of GNSSR for accurate soil moisture retrieval. These advancements not only highlight the significance of cutting-edge remote sensing methodologies but also open new avenues for future investigations in soil moisture monitoring and its relevance to climate change and ecological processes[8].

2.2 Google Earth Engine for Agricultural Applications:

Google Earth Engine (GEE) has become a groundbreaking tool for extensive geospatial analysis, offering access to vast archives of satellite imagery and cloud-computing resources. This platform has greatly improved the precision and accuracy of agricultural functions, especially in mapping cropland extent. Research conducted by Xiong et al. in 2017 showcased GEE's ability to produce high-resolution cropland extent maps throughout Africa by utilizing both Sentinel-2 and Landsat 8 data. Their methodology effectively tackled the obstacles associated with smallholder farming systems and achieved an impressive overall accuracy of 94%, highlighting GEE's potential for analyzing food security[9].

Additionally, Pande et al. in 2023 illustrated an innovative application of GEE in land use and land cover (LULC) mapping by using a Classification and Regression Tree (CART) model to evaluate land cover changes during the winter season in Maharashtra, India. Their findings resulted in training accuracies of 100% and validation accuracies ranging from 89% to 94%, demonstrating GEE's reliability in hydrological studies. This consistent level of high accuracy in LULC mapping is vital for effective management of water resources and environmental conservation, underscoring GEE's role in enhancing agricultural research and practices. In summary, integrating GEE into agricultural applications marks a significant advancement in the realm of remote sensing and geospatial analysis[10].

2.3 Time-Series Analysis and Forecasting:

TSA (time series analysis) of soil moisture has gained considerable attention for agricultural forecasting applications, particularly due to its critical role in enhancing irrigation efficiency and ensuring food security. Integration of seasonal integrated moving average (ARIMA) model with water balance equations has been shown to increase the accuracy of the predictions at different soil depths. For instance, a recent study demonstrated that a novel soil moisture prediction model, which incorporates depth parameters, outperformed the traditional seasonal ARIMA model, particularly at depths of 40 cm, 100 cm, and 200 cm (Fu et al., 2023). This model effectively captures seasonal trends in soil moisture fluctuations, revealing that moisture independence from external influences increases with depth[11].

In addition, a combination of ARIMA and backpropagation neural nets (BP neural nets) was proposed to address both linear and non-linear soil moisture data characteristics. This hybrid approach has yielded significant improvements in prediction accuracy, with an average relative error of just 1.51%, outperforming standalone ARIMA and BP models (Wang et al., 2023). Such advancements not only facilitate better water resource management but also contribute to the development of water-saving agricultural practices, ultimately supporting sustainable agricultural productivity[12].

2.4 Satellite-Based Soil Moisture Monitoring in North Gujarat:

Monitoring soil moisture using satellite technology has become an essential resource for managing agriculture and assessing drought conditions in semiarid areas. The use of remote sensing methods to estimate soil moisture offers crucial information for water resource management, especially in regions such as North Gujarat, where agricultural output heavily depends on the availability of soil water. This literature review explores the current landscape of research related to satellite-based soil moisture monitoring, with a particular emphasis on North Gujarat and comparable semiarid regions.

The basis of satellite-based soil moisture monitoring is grounded in the principles of microwave remote sensing. Petropoulos et al. (2015) conducted an extensive review of soil moisture retrieval from spaceborne passive microwave observations, demonstrating its utility[13]. Their findings underscored the capability of L-band radiometry to penetrate through vegetation canopies and provide accurate measurements of soil moisture across various land cover types. The study emphasized the importance of algorithm development for improving retrieval accuracy in heterogeneous landscapes, which is particularly relevant for the diverse agricultural systems found in North Gujarat.

Regional applications of satellite-based soil moisture monitoring in Gujarat have shown promising results for drought assessment and agricultural planning. Shah et al. (2018) analysed drought patterns in Gujarat using meteorological data and vegetation indices derived from satellite observations, demonstrating the utility of remote sensing approaches for understanding spatiotemporal drought dynamics in the region[14]. Their research revealed significant correlations between satellite-derived indices and ground-based meteorological measurements, establishing a foundation for operational drought monitoring systems in Gujarat's agricultural areas.

The integration of multiple satellite platforms has enhanced soil moisture monitoring capabilities, as explored by Peng et al. (2021) in their study of “SMAP and MODIS data fusion” for high-resolution soil moisture mapping. Their research demonstrated improved spatial and temporal resolution through data fusion techniques, which addresses one of the primary limitations of individual satellite missions. This approach is particularly valuable for the North Gujarat regional studies where information on soil moisture at field level is essential for accurate agricultural applications.

Validation of satellite derived soil moisture products requires extensive data on the ground, as Kolassa et al. have stressed. (2017) in their comprehensive assessment of the SMAP soil moisture uptake in different climatic regions[15]. Their analysis revealed varying performance of satellite algorithms across different environmental conditions, with semi-arid regions showing moderate to good correlation with in-situ measurements. This finding has important implications for North Gujarat, where the semi-arid climate presents unique challenges for satellite-based soil moisture estimation.

Machine learning approaches have shown considerable potential to improve soil moisture-measuring algorithms, as demonstrated by Adab et al. (2020) which used ANN-“artificial neural networks” and SVM-“support vector machines” to estimate soil moisture using multi-spectral satellite data[16]. Their study achieved improved accuracy compared to traditional empirical approaches, particularly in areas with complex terrain and vegetation patterns. These advanced methodologies offer promising avenues for enhancing soil moisture monitoring capabilities in the heterogeneous landscape of North Gujarat.

The operational implementation of satellite-based soil moisture monitoring systems requires consideration of local environmental conditions and user requirements. Raki et al. (2018) developed a methodology for retrieving soil moisture from Landsat data in semi-arid regions, focusing on the practical aspects of algorithm implementation and validation[17]. Their work demonstrated the feasibility of using moderate-resolution satellite data for regional soil moisture monitoring, providing a framework that could be adapted for North Gujarat's specific environmental conditions.

Despite significant advances in satellite-based soil moisture monitoring, several challenges remain for regional applications in North Gujarat. These include the need for improved spatial resolution, better understanding of local soil properties and vegetation dynamics, and development of region-specific calibration procedures. Future research should focus on the integration of multiple data sources, the development of operational monitoring systems and the establishment of comprehensive soil validation networks to support the satellite-based soil moisture monitoring in this important agricultural region.

III. METHODOLOGY

3.1 Data Sources:

The soil moisture datasets utilized in this study were sourced from the Soil Moisture Active Passive (SMAP) mission developed by NASA, which provides global, high-resolution measurements of both surface (top 5cm) and root zone (up to 1m depth) soil moisture content. SMAP utilizes L-band passive and active microwave sensing to generate spatially continuous, temporally frequent (typically 2-3 day revisit) soil moisture estimates, making it an ideal choice for monitoring dynamic soil moisture fluctuations in agricultural regions such as North Gujarat. To complement soil moisture analysis with atmospheric inputs, precipitation data were obtained from the Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS), accessed via Google Earth Engine (GEE). CHIRPS combines satellite imagery, in situ station data, and cloud computing algorithms to generate rainfall estimates at fine spatial (0.05°) and temporal (daily) resolutions. The integration of NASA SMAP and CHIRPS data within the GEE environment enabled efficient retrieval, preprocessing, and fusion of multi-source geospatial datasets, facilitating robust spatio-temporal analysis and forecasting of soil moisture variability relevant to local agrometeorological management.

3.2 Workflow:

This part describes the theoretical approach used in the suggested framework for soil analysis. The methodology has been structured as a modular pipeline in Python, which incorporates the retrieval of geospatial data, preprocessing, feature extraction, and analytical visualization. The overall workflow is depicted in the flow diagram in Figure 1.

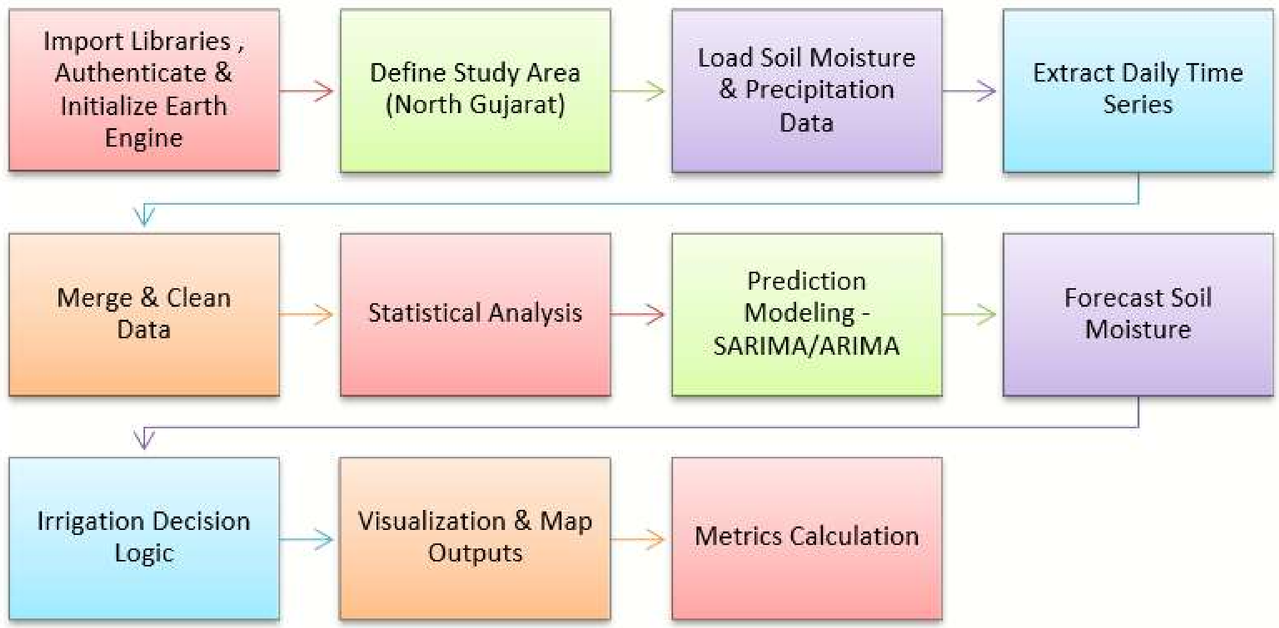

FIGURE 1: Framework for Soil Analysis

The project workflow begins with acquiring satellite datasets from Google Earth Engine (GEE), specifically soil moisture and rainfall data relevant to the study area. These raw datasets undergo cleaning and merging to create comprehensive, continuous time-series tables that integrate multiple variables. Following data preparation, in-depth analyses are performed, including correlation assessments between rainfall and soil moisture, stationarity testing to understand the time-series properties, trend extraction to identify underlying patterns, and anomaly detection to flag unusual soil moisture events. Next, advanced time-series models such as SARIMA and ARIMA are trained and tested on the processed data to capture temporal dynamics and improve predictive accuracy. Using the optimized model, the system forecasts future soil moisture levels, which feed into an irrigation decision-making module that applies predefined logic to determine whether irrigation should be turned ON or OFF based on current and predicted conditions. The results of these analyses and decisions are then communicated through detailed visualizations, including graphs of soil moisture trends and interactive spatial maps. Finally, the process concludes with a comprehensive report summarizing key metrics such as average moisture levels, forecast accuracy, anomaly counts, and model performance, thereby providing actionable insights for effective irrigation management.

3.3 Data Acquisition and Preprocessing:

The study used satellite data to analyse soil moisture dynamics and precipitation patterns in the Northern Gujarat region.

Two primary data sources have been used: NASA “Soil Moisture Active Passive” (SMAP) provides data on surface moisture (sm_surface) and soil moisture (sm_rootzone) in the climatic disaster zone. “Climate Hazards Group InfraRed Precipitation with Station data” (CHIRPS) provides high resolution daily rainfall estimates.

The spatial domain was defined as a rectangular bounding box encompassing North Gujarat, with latitude and longitude boundaries explicitly set to limit data extraction. The temporal coverage spanned from January 1, 2023, to August 9, 2025.

FIGURE 2: Study area in spatial domain as a rectangular bounding box

The datasets were programmatically accessed and processed using the Google Earth Engine (GEE) API. Daily average soil moisture and precipitation values were extracted by aggregating pixel values over the entire study area. The extracted time-series data were organized into pandas DataFrames, ensuring continuous daily records by filling missing values where applicable.

3.4 Data Integration and Analysis:

The soil moisture and precipitation datasets were merged into a unified time-series to facilitate joint analysis. Rainfall data were resampled as daily sums, with missing rainfall days imputed as zeros. A correlation analysis using Pearson correlation coefficients quantified the relationship between rainfall and soil moisture variation, revealing moderate positive associations (rainfall vs. surface moisture ≈ 0.25, rainfall vs. root zone moisture ≈ 0.12), indicative of rainfall's influence on soil moisture alongside other environmental factors.

3.5 Visualization and Reporting:

Comprehensive visualization tools facilitated interpretation and presentation of results:

- **Time-Series Plots**: Displayed observed soil moisture, smoothed trends, forecasted values with confidence intervals, and marked anomalies.
- **Irrigation Events**: Irrigation ON/OFF decisions were visually annotated on plots.
- **Spatial Maps**: Interactive folium maps depicted the spatial distribution of soil moisture across the study region using latest satellite data.

3.6 Time-Series Modeling and Forecasting:

A dedicated Soil Moisture Analyzer class was developed to conduct advanced time-series analyses and forecasting, encompassing the following key components:

- **Normalization**: Soil moisture values have been scaled from 0 to 1 in preparation for the modelling exercise.
- **Stationarity Testing**: The Augmented Dickey-Fuller (ADF) test assessed whether the soil moisture time-series exhibited consistent temporal patterns or random fluctuations.
- **Trend Estimation**: Seven-day moving averages smoothed the soil moisture data to highlight underlying trends.
- **Anomaly Detection**: Days with soil moisture values significantly deviating from historical averages were flagged as anomalies.
- **SARIMA Model Optimization**: Multiple seasonal autoregressive integrated moving average (SARIMA) models with varying parameters (p, d, q) were fitted, with the optimal model selected based on Akaike Information Criterion (AIC) minimization.
- **Forecasting**: The SARIMA model, incorporating forecasted rainfall as an exogenous input, predicted soil moisture for the subsequent week. Forecast intervals at 95% confidence levels were generated.
- **Model Comparison**: Forecasting accuracy of the SARIMA model was compared against a simpler ARIMA model using root mean square error (RMSE) and mean absolute error (MAE) on held-out test data.

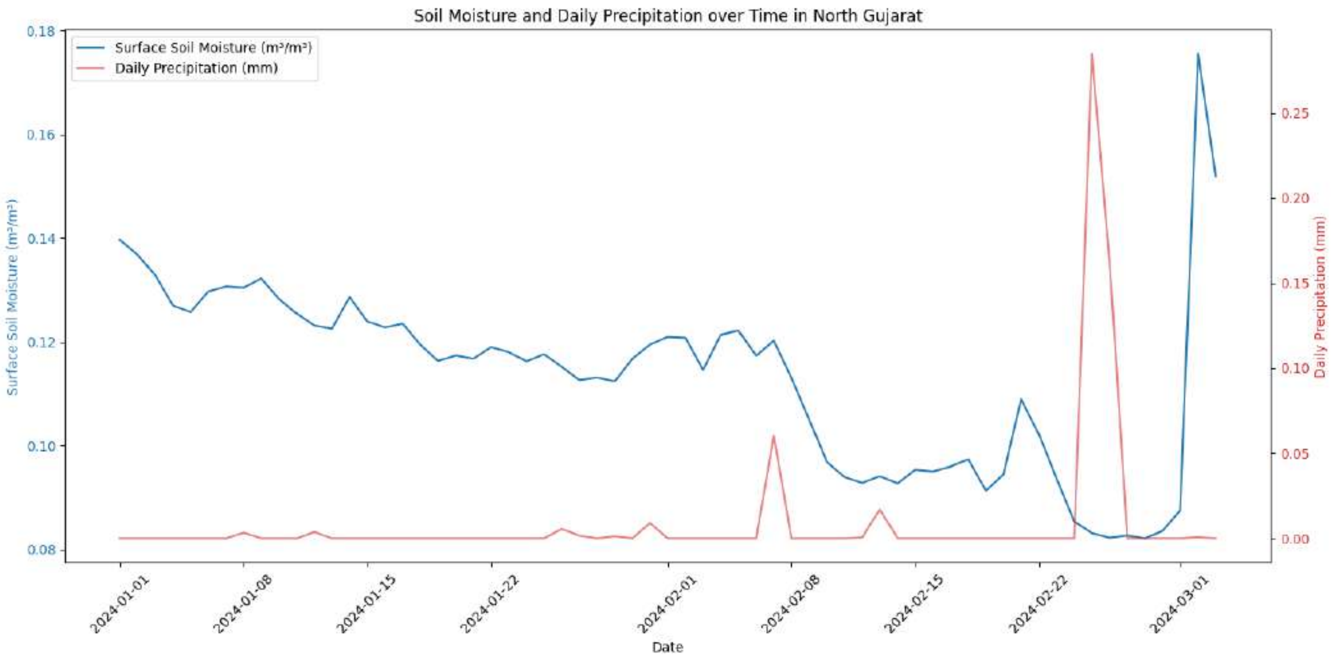

FIGURE 3: Time-series plot of surface and rootzone soil moisture in North Gujarat

3.7 Irrigation Decision Support System:

An IrrigationController class implemented rule-based irrigation decisions based on current observations and forecasted conditions. Thresholds for soil moisture (e.g., 0.2 for surface and 0.25 for root zone) were predefined. The decision logic considered:

Decision Rules:

IF (current_surface < 0.2 OR current_rootzone < 0.25)

AND (forecast_mean < threshold)

AND (2-day cumulative precipitation < 2.0 mm)

THEN "Turn ON irrigation"

ELSE "Turn OFF irrigation"

The system issued irrigation ON commands when dry conditions and low rainfall forecasts were detected, and OFF commands when moisture levels recovered or rainfall was sufficient.

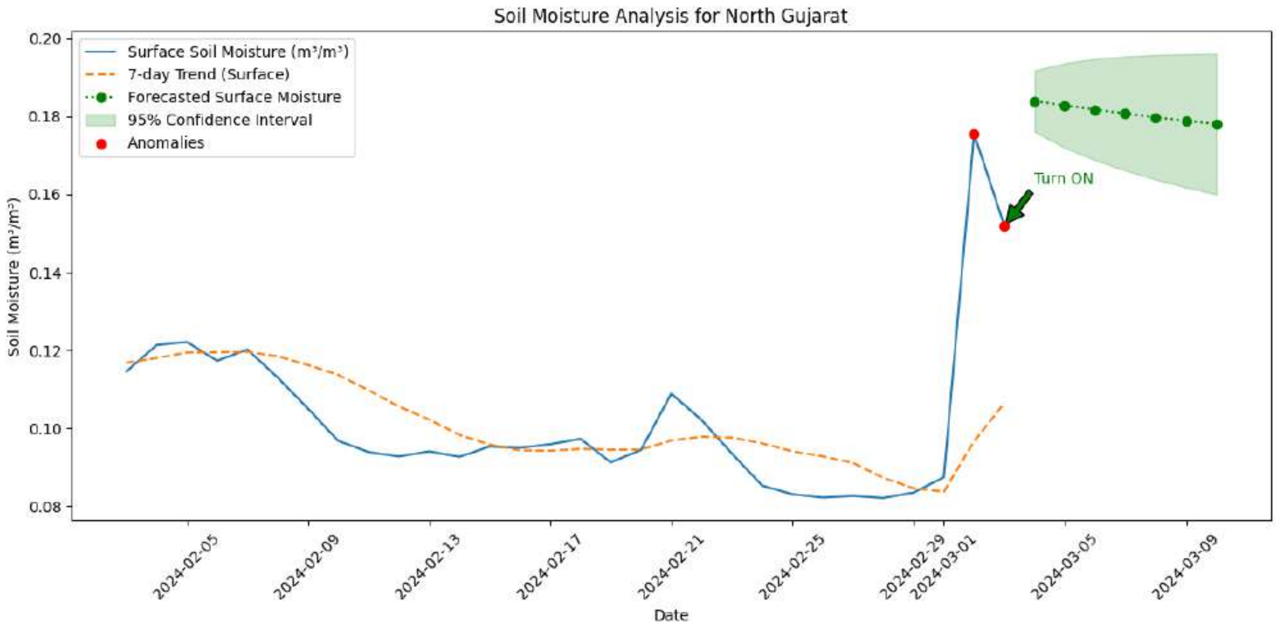

FIGURE 4: Irrigation ON/OFF decisions

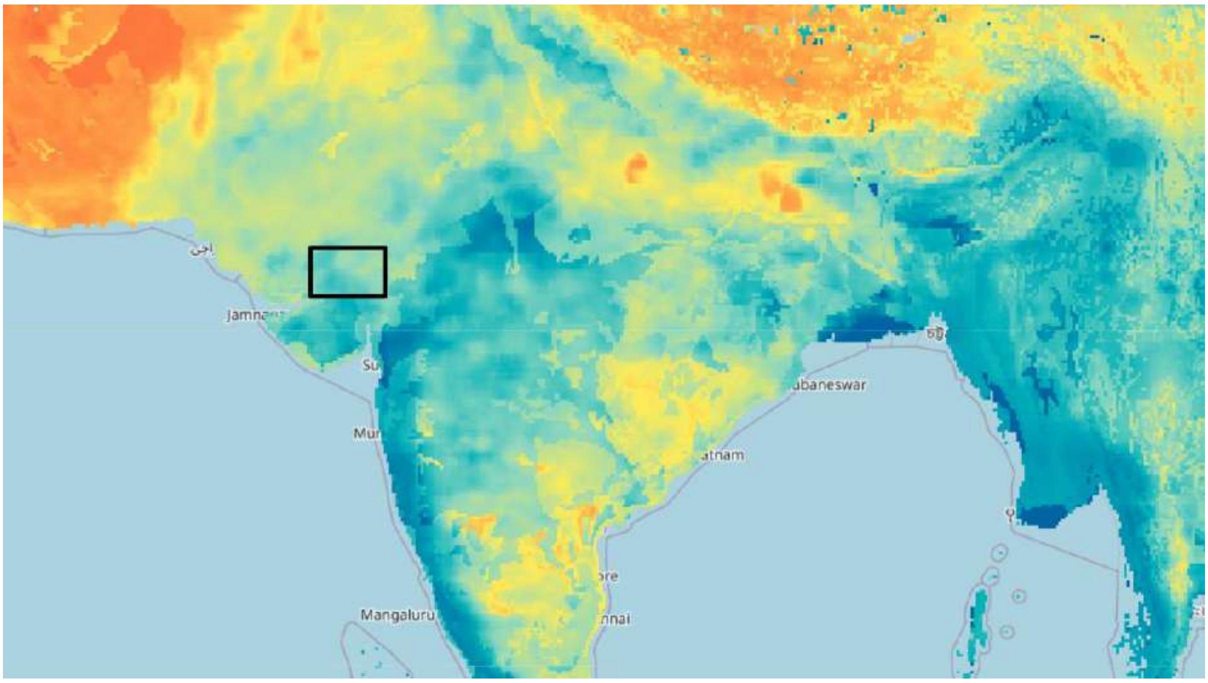

FIGURE 5: Spatial distribution of soil moisture (Folium map snapshot).

Additionally, summary metrics such as mean soil moisture, trend values, anomaly counts, and stationarity test results were computed to provide high-level insights.

IV. RESULTS AND DISCUSSION

The proposed soil moisture monitoring framework was applied to the **North Gujarat** region using Google Earth Engine datasets, integrating **surface soil moisture**, **rootzone moisture**, and **precipitation** data.

4.1 Statistical Insights:

TABLE 1
STABLE SOIL MOISTURE CONDITIONS VALUES

Metric	Value	Unit
Precipitation vs Surface Correlation	0.254	-
Precipitation vs Rootzone Correlation	0.122	-
ADF Statistic	-2.30	-
p-value (stationarity)	0.17	-
Mean Surface Moisture	0.088	m^3/m^3
Mean Rootzone Moisture	0.158	m^3/m^3
Surface Trend (7-day MA)	0.073	m^3/m^3
Rootzone Trend (7-day MA)	0.149	m^3/m^3
Anomaly Count (30-day)	0	count

These results indicate stable soil moisture conditions over the last month with gradual upward trends in both surface and root zone moisture levels.

4.2 Model Optimization and Performance:

Time-series forecasting models were evaluated to predict future soil moisture. The SARIMA model, incorporating exogenous precipitation data, was optimized to order (1, 0, 1) with no seasonal components (0, 0, 0, 7). For benchmarking, a basic ARIMA model without exogenous inputs was also trained.

The performance metrics were as follows:

- **SARIMA Model**: RMSE = 0.0781, MAE = 0.0615
- **Basic ARIMA Model**: RMSE = 0.0716, MAE = 0.0556

Although the basic ARIMA model showed slightly better error metrics on the test data, SARIMA's inclusion of rainfall information provides greater interpretability and adaptability for irrigation decision-making.

4.3 Forecasting and Irrigation Decision:

A three-day forecast with a 95% confidence interval (±0.015 m^3/m^3) indicated soil moisture levels above the irrigation threshold.

Decision Rule:

If predicted soil moisture < threshold → Turn ON irrigation.

Else → Turn OFF irrigation.

Based on forecast output, irrigation remained OFF for the forecast period.

This comprehensive analysis demonstrates the efficacy of integrating satellite data and time-series modeling to monitor and predict soil moisture conditions. The approach provides actionable insights for automated irrigation management, supporting water-efficient agriculture in semi-arid regions such as North Gujarat.

V. CONCLUSION

This study demonstrates the effectiveness of combining NASA's SMAP data, GEE processing capabilities, and SARIMA-based forecasting for soil moisture monitoring in semi-arid regions. The integration with irrigation decision-support logic has the potential to optimize agricultural water use in North Gujarat. Future work will focus on extending the model with machine learning approaches and integrating crop growth models.

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CONFLICTS OF INTEREST

The authors declare no financial involvement, competing financial interests, or personal relationships that could have influenced the work reported in this paper.

REFERENCES

[1] S. I. Seneviratne *et al.*, "Investigating soil moisture–climate interactions in a changing climate: A review," *Earth-Science Rev.*, vol. 99, no. 3, pp. 125–161, 2010, doi: https://doi.org/10.1016/j.earscirev.2010.02.004.

[2] A. Porporato, E. Daly, and I. Rodriguez-Iturbe, "Soil water balance and ecosystem response to climate change.," *Am. Nat.*, vol. 164, no. 5, pp. 625–632, Nov. 2004, doi: 10.1086/424970.

[3] W. Dorigo *et al.*, "ESA CCI Soil Moisture for improved Earth system understanding: State-of-the art and future directions," *Remote Sens. Environ.*, vol. 203, pp. 185–215, 2017, doi: https://doi.org/10.1016/j.rse.2017.07.001.

[4] J. Rockström *et al.*, "Managing water in rainfed agriculture-The need for a paradigm shift," *Agric. Water Manag.*, vol. 97, no. 4, pp. 543–550, 2010, doi: 10.1016/j.agwat.2009.09.009.

[5] R. S. Singh, J. T. Reager, N. L. Miller, and J. S. Famiglietti, "Toward hyper-resolution land-surface modeling: The effects of fine-scale topography and soil texture on CLM4.0 simulations over the Southwestern U.S.," *Water Resour. Res.*, vol. 51, no. 4, pp. 2648–2667, 2015, doi: 10.1002/2014WR015686.

[6] Y. Feng, N. Cui, L. Zhao, X. Hu, and D. Gong, "Comparison of ELM, GANN, WNN and empirical models for estimating reference evapotranspiration in humid region of Southwest China," *J. Hydrol.*, vol. 536, pp. 378–384, 2016, doi: 10.1016/j.jhydrol.2016.02.053.

[7] K. Edokossi, A. Calabia, S. Jin, and I. Molina, "GNSS-reflectometry and remote sensing of soil moisture: A review of measurement techniques, methods, and applications," *Remote Sens.*, vol. 12, no. 4, 2020, doi: 10.3390/rs12040614.

[8] C. Yin *et al.*, "Intercomparison of soil moisture retrieved from GNSS-R and from passive L-band radiometry at the valencia anchor station," *Sensors (Switzerland)*, vol. 19, no. 8, pp. 1–16, 2019, doi: 10.3390/s19081900.

[9] J. Xiong *et al.*, "Nominal 30-m cropland extent map of continental Africa by integrating pixel-based and object-based algorithms using Sentinel-2 and Landsat-8 data on google earth engine," *Remote Sens.*, vol. 9, no. 10, pp. 1–27, 2017, doi: 10.3390/rs9101065.

[10] C. B. Pande *et al.*, "Impact of land use/land cover changes on evapotranspiration and model accuracy using Google Earth engine and classification and regression tree modeling," *Geomatics, Nat. Hazards Risk*, vol. 15, no. 1, p. , 2024, doi: 10.1080/19475705.2023.2290350.

[11] R. Fu, L. Xie, T. Liu, B. Zheng, Y. Zhang, and S. Hu, "A Soil Moisture Prediction Model, Based on Depth and Water Balance Equation: A Case Study of the Xilingol League Grassland," *Int. J. Environ. Res. Public Health*, vol. 20, no. 2, 2023, doi: 10.3390/ijerph20021374.

[12] G. Wang, Y. Han, and J. Chang, "Research on soil moisture content combination prediction model based on ARIMA and BP neural networks," *Adv. Control Appl. Eng. Ind. Syst.*, vol. 6, no. 2, pp. 1–12, 2024, doi: 10.1002/adc2.139.

[13] G. P. Petropoulos, G. Ireland, and B. Barrett, "Surface soil moisture retrievals from remote sensing: Current status, products & future trends," *Phys. Chem. Earth, Parts A/B/C*, vol. 83–84, pp. 36–56, 2015, doi: https://doi.org/10.1016/j.pce.2015.02.009.

[14] R. Shah, N. Bharadiya, and V. Manekar, "Drought Index Computation Using Standardized Precipitation Index (SPI) Method For Surat District, Gujarat," *Aquat. Procedia*, vol. 4, no. December, pp. 1243–1249, 2015, doi: 10.1016/j.aqpro.2015.02.162.

[15] J. Kolassa, P. Gentine, C. Prigent, F. Aires, and S. H. Alemohammad, "Soil moisture retrieval from AMSR-E and ASCAT microwave observation synergy. Part 2: Product evaluation," *Remote Sens. Environ.*, vol. 195, pp. 202–217, 2017, doi: https://doi.org/10.1016/j.rse.2017.04.020.

[16] H. Adab, R. Morbidelli, C. Saltalippi, M. Moradian, and G. A. F. Ghalhari, "Machine learning to estimate surface soil moisture from remote sensing data," *Water (Switzerland)*, vol. 12, no. 11, pp. 1–28, 2020, doi: 10.3390/w12113223.

[17] A. Amazirh *et al.*, "Retrieving surface soil moisture at high spatio-temporal resolution from a synergy between Sentinel-1 radar and Landsat thermal data: A study case over bare soil," *Remote Sens. Environ.*, vol. 211, no. June, pp. 321–337, 2018, doi: 10.1016/j.rse.2018.04.013.

Livelihood Vulnerability Levels of Smallholder Farmers to Climate Change in Selected Parts of Makueni County, Kenya

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Abstract— *Climate change poses a significant threat to smallholder farmers' livelihoods, particularly in arid and semi-arid regions such as Kenya's Makueni County, where rain-fed agriculture dominates. Increasing rainfall variability, recurrent droughts, and extreme temperatures have undermined food security, incomes, and resilience. This study assessed livelihood vulnerability to climate change in three agro-ecological zones, Mbooni (semi-humid), Makueni (semi-arid), and Kibwezi East (arid), focusing on exposure, sensitivity, and adaptive capacity. Guided by the Sustainable Livelihoods Approach and using the Livelihood Vulnerability Index (LVI) framework, a descriptive mixed-methods design was employed. Data from 289 smallholder households were collected through questionnaires, focus group discussions, and key informant interviews, with quantitative analysis conducted in SPSS and qualitative data thematically analyzed. Results showed that 76.8% of farmers experienced extreme weather, with water scarcity emerging as the most critical vulnerability. Key indicators influencing vulnerability included high dependency ratios, female-headed households, limited crop diversity, low grain storage capacity, reliance on own-farm production, long distances to healthcare facilities, and weak access to credit and extension services. Adaptive capacity was constrained by inadequate irrigation infrastructure, limited non-farm income opportunities, and underutilization of indigenous knowledge. The study recommends strengthening water infrastructure, promoting drought-tolerant crops and diversified farming systems, improving access to agricultural finance, and integrating climate-smart practices into extension services. Policy interventions should embed climate adaptation into county development plans and enhance social safety nets to protect the most vulnerable. Such measures are vital for safeguarding livelihoods and sustaining agricultural productivity amid intensifying climate risks.*

***Keywords*— Smallholder farmers, vulnerability levels, climate change, Makueni County, Kenya.**

I. INTRODUCTION

Climate Change has been known to be one of the most pressing complexes and perplexing global environmental challenge (FAO, 2010), threatening food security, poverty alleviation, and livelihoods for smallholder farmers. Climate change has led to adverse effect to every region across the globe, with many irreversible changes, such as the rise of CO_2 concentrations in the atmosphere, increase of the global surface temperatures and also the rise of the global mean sea levels (Intergovernmental Panel on Climate Change –(IPPC), 2021), and therefore, disrupting the global movement towards sustainable development (Harvey *et al.,* 2018). Evidence of experienced climatic changes across the entire globe of extreme events such as heavy precipitation leading to floods, heatwaves, droughts and tropical cyclones has strengthened and are more likely to reach unbearable threshold for agriculture, health and may also lead to adverse effect to natural water cycle (IPPC, 2021). In the recent years, the world has grappled around the effects related to changes of climate in all the main economic areas, including agriculture, which is the mainstay for more than 475 million smallholder farmers across the globe (Harvey *et al.,* 2018). As explained by Donattia *et al.,* 2019), agriculture contributes about 60% of the world's workforce, providing about eighty percent of the food for domestic consumption in the third world countries.

The Africa's Agenda 2063, which was concluded in 2013, recognized change in climate as a major challenge for the continent's progress and growth. Africa's economy highly depends on agriculture accounts for the majority of livelihoods, therefore, an exposure and vulnerability hot spot for climate change impacts and variability. Decreased crop production coupled with increased temperature and drought pressure, increased pest damage and disease damage, flood effects on food system infrastructure, leading to serious consequences for food security and health are major agricultural threats at the regional cascading to local levels. Promotion of socioeconomic growth mostly in the agronomic sector is one of the promising approaches towards reducing climate related risks, poverty and extreme event impacts throughout the continent (UN, 2020).

Kenya has been impacted negatively by climate change due to its nascent economic growth trends. Majority of Kenyan agriculture totally relies on rainfall, with only less than 5% under irrigation, and the sector has suffered from increasing variability in rainfall. Floods and drought which constitute some of the climatic extreme events have negative impacts on the socio-economic development, with devastating consequences on the country's economy (SEI, 2009; Government of Kenya – (G.O.K), 2010; G.O.K, 2019). Agricultural activities are the main sources of economic growth, livelihood, food security, foreign construction and job creation, and foreign exchange earnings for the majority of the population of Kenya (KEPSA, 2014; Ochieng *et.al.*, 2016). Demand for food, fuel wood and forest products has increased tremendously over the years, leading to unprecedented environmental degradation. An estimation of over 57% of Kenyan population lives below poverty line (FAO, 2010) while, most of smallholder farmers (70%), basically rely on climate-sensitive economic activities including agriculture (Simotwo *et al.,* 2018; Ylva *et.al.,* 2020), therefore, increasing farmers' vulnerability and affecting the Sustainable Development Goal (SDG) 13, Target 13.1, that is aimed at strengthening adaptability and resilience so as to enable farmers respond to risks associated to climate change and natural calamities (GOK, 2018).

The study aimed to examine how variability as well as change in climate influences smallholder agriculturalists in the study area and how these changes have influenced their livelihood vulnerability. It also sought to assess the current mitigation strategies to changes in climate in order to make recommendations on the appropriate adaptation measures and coping mechanisms. According to Mogelgaard *et al.* (2018) resilience of development outcomes can be improved by mainstreaming climate adaptation actions into progressive growth plans and strategies, leading to the effective utilization of available natural resources, while avoiding investments that could lead to serious harm.

Hahn and colleagues (2009) developed the Livelihood Vulnerability Index (LVI), based on Sustainable Livelihoods Approach (SLA) which typically emphasize on the five capitals, namely, environmental, financial, social, human and physical built by Conway and Chambers (Minh *et al*., 2019). The SLA approach has been used successfully within United Nations agencies and other international development organizations for planning and assessing households' ability to withstand shocks like natural disasters, which include climate change, epidemics and even civil conflicts (Hahn *et al.,* 2009; Minh *et al.,* 2019). SLA to some extent discourses aspects of sensitivity and adaptive capacity to climate change issues, but it is limited to address exposure (Hahn *et al.,* 2009).

The LIV, therefore, describes these previous methods of incorporating the various influences of climate change as well as variables that take the level of exposure to natural disasters, their sensitivity to the impacts associated with changing climate and dynamics of household capacity to cope (Hahn *et al.,* 2009). With such elaborate method, it has become possible for researchers to evaluate livelihoods risks from climate change with increased precision and improved accuracy for better planning and better mitigation and adaptation strategies recommendations (Etwire *et al.*, 2013; Hahn *et al.*, 2009; Minh *et al.*, 2019).

The LIV is easier to compute, its strengths lie in the fact that it predominantly uses primary data, it captures in wide context the susceptibility to droughts, floods, climate change, conflicts and a wide range of other natural disasters (Hahn *et al.*, 2009). It effectively transcends postulated hypothesis inherent in earlier methods in its ability to account existing susceptibility that is critical and more valuable for present and timely planning. Many studies have shown the secondary data hitherto relied upon extensively in the earlier approaches suffered from lack of regular update, hence compromising the quality of findings and proposed strategies and recommendations (Hahn *et al.*, 2009; Etwire *et al.*, 2013).

II. METHODS

2.1 General Study Area:

Makueni County is among the 47 counties in Kenya, located in the South Eastern region. The neighbourhood include Kitui County to the East, Kajiado County to West, Machakos County to the North and Taita Taveta County to the south. It has an area of 8,008.7 KM^2 and is between Latitude 1º 35 ′ and 3 ° 00 ′ South as well as Longitude 37º10 'and 38º 30 ′ East. The county experience frequent droughts as it is in the Arid and Semi-Aid area. It has six sub-counties including Makueni, Kibwezi East, Kaiti, Mbooni, Kilome and Kibwezi West sub-counties. The county is then sub-divided in to further 30 wards, containing 60 sub-wards (G.O.K, 2013).

The study was done in selected parts of Makueni County which were classified according to agro-ecological zones (Maluki, *et al.,* 2016). The agro-ecological zones were classified as Semi Humid zone (upper part) covering Mbooni Sub County area, Semi-Arid areas (middle part) which covered Makueni Sub County and Arid area (lower part) which covered Kibwezi East Sub County.

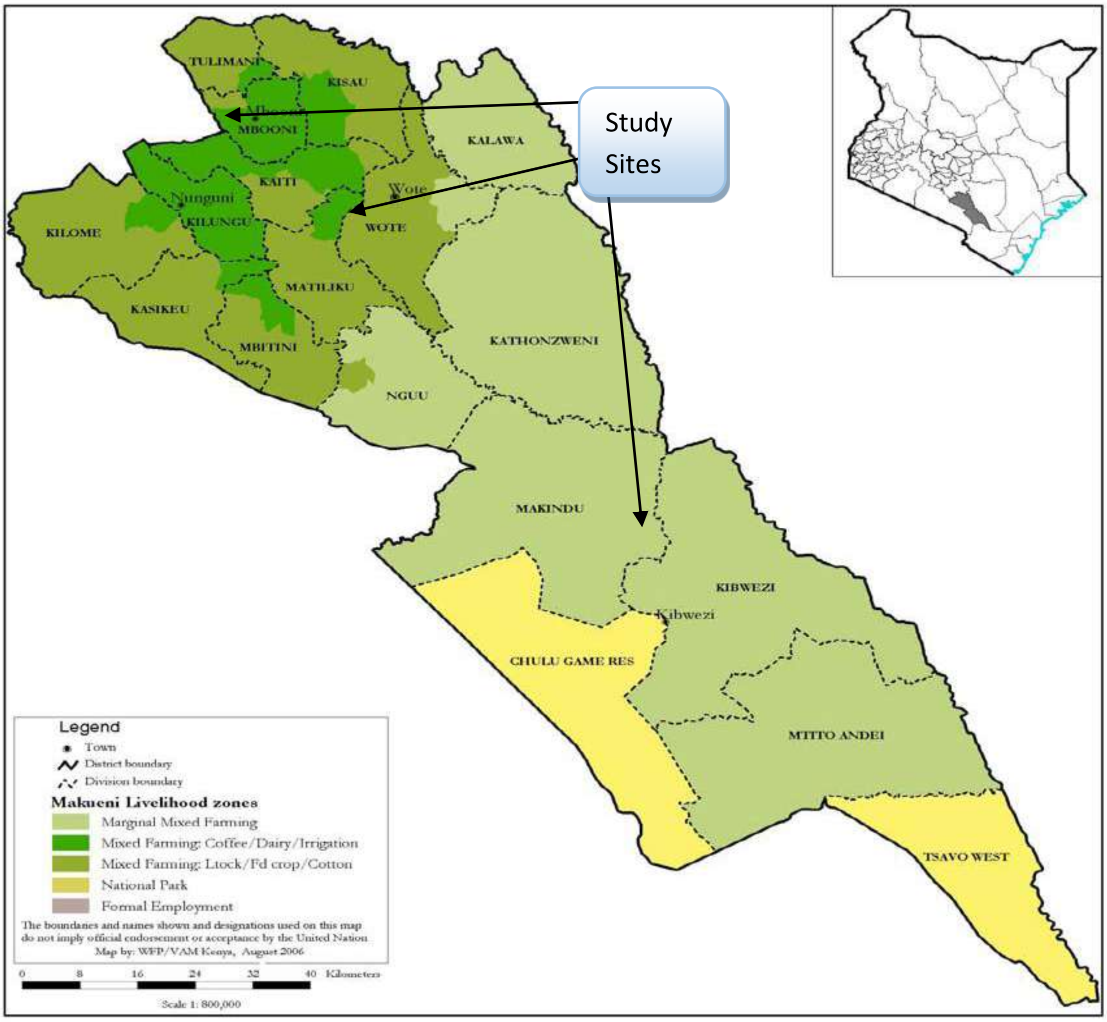

FIGURE 1: A Map of Makueni Livelihood Zones
Source: Makueni LRA Report, 2013.

2.2 Research Design:

Descriptive research design was embraced to examine and calculate the susceptibility of smallholder farmers due to changes in climate and variability, including factors that affect their vulnerability. The design was also used to explore their climate change strategies (Asfaw *et al.*, 2021). Mixed methods of both quantitative and qualitative methods were used to collect primary data. Information was collected from family heads regarding socio-economic, biophysical and demographic factors of the study area.

2.3 Sample frame and sampling techniques:

The sample frame for the study was drawn from farmer beneficiaries from the Kenya Cereals Enhancement Program – Climate Resilient Agricultural Livelihood (KCEP-CRAL). KCEP-CRAL is a national government funded and implemented program in selected counties in Kenya, with Makueni county being a beneficiary. KCEP-CRAL program, which kicked off in 2018 in Makueni, aimed at reducing rural poverty and food insecurity among smallholder farmers in arid and semi-arid lands by developing their economic potential, while improving their natural resource management capacity and resilience to climate change in an increasingly fragile ecosystem. At least 16,000 subsistence farmers benefited from the program through the provision of farm inputs through e-voucher system, financial inclusion, post-production management practices and market linkages for targeted value chains, along with other agricultural resources to enhance their resilience. The current study dwelt on three sub-counties selected on the basis of their agro-ecological zone localities and which were beneficiaries of the KCEP-CRAL program.

TABLE 1
SAMPLING FRAME OF FARMER BENEFICIARIES FROM KCEP-CRAL PROGRAM

Area (Sub- County)	KCEP-CRAL Beneficiaries	Percentage
Mbooni Sub- County	140	44.9
Muvau Sub- County	79	25.3
Masongaleni Sub- County	93	29.8
Totals	312	100.0

Source: Ministry of Agriculture Makueni County

The survey research used a randomized multi-stage sampling process to select households (Asfaw *et al.,* 2021).

2.4 Sample Size Determination:

The following formula was embraced for the study (Asfaw *et al.,* 2021).

$$n = \frac{Z^2 * N * p * q}{e^2(N-1) + Z^2 * p * q} \quad (1)$$

Where; N represents the total targeted population for smallholder farmers, n is the sample size, and Z is the set standard deviation picked at 95% confidence level, which is 1.96. *P* is the alpha levels of 0.5, showing the estimated proportion present while *q* (1-p)(0.5) represents the estimated proportion of the attribute not present in the population, while *e* is the required accuracy level, usually set as 0.05 (5% of acceptable sample error). From the calculations, the entire sample size was 244 households spread at 140 for Mbooni, 79 for Makueni and 93 for Kibwezi East.

2.5 Research Instruments:

A household questionnaire was used for the study. The questionnaire divided into five sections. The first section captured household demographic information. The second section was capturing household general information, while section three was capturing socioeconomic activities and livelihood options. Section four was on adaptations to climate change and variability. The last section was on institutional support. The questions were distributed across the five sections capturing demographics and socio-economic responses, their livelihoods, outcomes and experiences of climate change in agriculture, land use practices related mitigations to climate actions provided by County Government and other climate actors in the study area.

2.6 Data Analysis:

The data collected was analyzed by both quantitative and qualitative approaches. The study used Statistical Package for Social Sciences (SPSS) software for analyzing data obtained from the questionnaire and the generated results were presented through tables and statistics.

A balanced weighted average method was embraced in this study to compute the LVI, which incorporates both the gap and the methods (Hahn *et al.,* 2009; Etwire *et al*., 2013). The authors emphasize that the gap method assesses vulnerability based on the deviation of vulnerable people living conditions and on standard living conditions when there are no changes in climate. The approach is grounded on accurately valuing each predictor variable based on its contribution to climate change and vulnerability to such people or groups.

The major components include several different indicators or sub-components, each sub-element contributing correspondingly to the general index. An easy-to-compute LVI formula uses an easy way to apply equivalent weights to all major elements. Similarly, each of these subdivisions is therefore measured on a different scale that needs to be standardized as an index using Eqn (1), which is commonly used in the human development indicator to compute life expectancy, and is also used in LVI risk assessment (Can *et al.,* 2013).

$$Index\ Sq = \frac{Sq - Smin}{Smax - Smin} \quad (2)$$

When S_q represents the index value of the sub-component indicator for q, and s_{min} and s_{max} are the lower and upper values, indicating the higher and lower vulnerability respectively of all readings. After each sub-components values are standardized, the value of each major value was calculated using Eqn. (2)

$$\text{Mq} = \frac{\sum_{i-1}^{n} index\ \text{Sq}}{n} \quad (3)$$

where M_q is one of the Twelve components of the tested area q, Water (W), Food (F), Health (H), Social Networks (SN), Livelihood Strategies (LS), Social Demographic Profile (SDP), Indeginous Knowledge (IK), Land (L), Environmental Resources (NR), Housing and Production (HP) or Finance and Income (FI), Natural Disasters and Climate Diversity (NDCV), for region q; $index_{sqi}$ represents the smallest parts, identified by i, that form each major component, and n is the number of sub-elements in each major element. When the values of each of the twelve major components are calculated, they were measured using Eqn (3) for the LVI of each location.

$$LVI = \frac{\sum_i^{11} Wmi\ Mqi}{\sum_i^{11} Wmi} \tag{4}$$

Also expressed as;

$$LVI = \frac{W_{SDP}SDP_q + W_{LS}LS_q + W_H H_q + W_{SN}SN_q + W_F F_q + W_W W_q + W_{IKS}IKS_q + W_L L_q + W_{NR}NR_q + W_{HP}HP_q + W_{FI}FI_q + W_{NDC}NDCV_q}{W_{SDP} + W_{LS} + W_H + W_{SN} + W_F W_W + W_{IKS} + W_L + W_{NR} + W_{HP} + W_{F1} + W_{NDC}} \tag{5}$$

LVI calculation-IPCC Framework Approach

In Eqn 4, where LVI_q is the studied location Livelihood Vulnerability, which is equal to the average of the twelve major elements. Weights of each major W_{Mi} element is determined by the other smaller elements that make up each major element. In addition, they were included to ensure that all sub-components contribute equally to LVI as a whole (Hahn *et al,* 2009; Sujakhu *et al,* 2019). Where LVI values range from 0 (Least vulnerable) to 0.5 (Most vulnerable) in calculations from statistics of Eqns (3) - (5), Hahn *et al*., (2009), another method (LIV-IPCC index) is used for new variables for LVI based on the IPCC definition of vulnerability and its tools for adaptive capacity, sensitivity and exposure (Etwire *et al.,* 2013; Sujakhu *et al.*, 2019). The adaptive capacity was framed on Socio-Demographic Profile, Livelihood Strategy and Social Networks. Exposure was incorporated into the framework of Natural Disaster and Climate Variability and Sensitivity on Food, Water and Health (Sujakhu *et al.,* 2019; Hahn *et al.*, 2009). The vulnerability index was calculated using Eqn 5 as shown.

$$\text{Vulnerability} = (\text{Adaptive capacity}) - (\text{Sensitivity} + \text{Exposure}) \tag{6}$$

In this study, *exposure* was measured using the number of adverse events (Drought and floods) over the past 5 years that occurred in the study area. Sensitivity was measured using food availability, water conditions and home health status. Adaptive capacity was measured using the demographic profile in the study area obtained from the study.

Climate variability was measured from secondary data sources using standard deviation of minimum and maximum value of monthly air temperatures as well as monthly precipitation in the last 5years. Instead of merging the major components into the LVI in Equation (4) in the LVI-IPCC approach, Eqn 6 integrates the critical contributing factors to climate change, which include the elements of sensitivity, exposure and adaptability, large components into three stages of exposure, and sensitivity. These are important factors that contribute to climate change as well as variability vulnerability (Etwire *et al.*, 2013; Gravitiani, *et al.*, 2017; Sujakhu *et al.,* 2019) as shown in Eqn 6 below.

$$CF_q = \frac{\sum_{i-1}^{n} W_{Mi}\,\mathrm{M}_q}{\sum_{i-1}^{n} W_{Mi}} \tag{7}$$

where CF_q represents factors contributing to exposure, sensitivity and adaptability of location d. M_{qi} is the main component of location q, denoted by i, W_{mi} is the weight of each major component and n is the number of major components for each contributing factor. The level of exposure, sensitivity and adaptability was calculated by combining three influential factors using Eqn 7 as shown.

$$LVI - IPCC_q = (e_q - a_q) * S_q \tag{8}$$

Where LVI_{IPCCq} is the local LVI for location q expressed using the IPCC vulnerability framework, e_q represent the calculated exposure score for location q (equal to the climate variability and natural disaster major component); a_q is the calculated capacity score for location q (weighted average of the social networks, livelihood strategies and socio-demographic major components) and sq is the calculated sensitivity score for location q (estimated health, water and food consumption major components) (Minh *et al.*, 2019; Hahn *et al.*, 2009). The LVI-IPCC scale ranges from -1 (Least vulnerable) to 1 (Most vulnerable). SPSS software was used to analyse and evaluate the livelihood vulnerability index.

2.7 Ethical Considerations:

The study was guided by research ethics. The six elements of research ethics were considered including informed consent, beneficence, confidentiality, anonymity, no harm and the right to withdraw from the exercise. Farmers, who were the main respondent, were first informed of the intentions and objectives of the study, requesting for their informed consent. Once the informed consent was given, then the other ethical considerations were also worked on. Confidentiality was also considered and adhered to, where information collected from farmers was not shared with third parties. The information collected was also kept confidential, as no farmer details were used to expose them to any unauthorized third party.

III. FINDINGS

3.1 Response rate and demographic characteristics of the respondents:

A sample of 289 respondents was reached and the target for each specified study area within the three agro-ecological zones is shown in Table 2 below.

TABLE 2
DISTRIBUTION AND RESPONSE RATE OF THE RESPONDENTS

Constituency (Ward)	Targeted sample size	Reached respondents	Percentage reached
Mbooni (Mbooni)	103	105	102
Makueni (Muvau)	66	79	120
Kibwezi East (Masongaleni)	75	105	140
Totals	**244**	**289**	**120**

The study response rate was 120% as six focus group discussions were reached instead of the initially intended five, which meets the threshold for sample size requirement according to Mugenda and Mugenda (2003).

3.2 Summary of demographic characteristics:

Most of the respondents were drawn from Kibwezi East and Mbooni (Table 3), both sub-counties having a representation of about 36.3%. Makueni had the least representation at 27.4%, in terms of relations to the household head. Majority of the respondents were spouses at 48.1%, while respondents who were the household heads were 38.1%. Further, there were 10.0% and 3.8% of the respondents who identified themselves as children and parents of the household heads. In terms of gender representation, more of the respondents at 64.0% were female, while the other 36% were male. In terms of level of education, majority of the respondents at 56.4% had achieved primary level education, followed by 29.8% who reported to have attained secondary education level. Respondents who had achieved college and university education were 5.5% and 1.4% respectively.

The distributions of respondents in terms of their age, the majority were aged between 26 to 40 years, representing 34.9% of the population. This category was followed by those aged between 41 to 60 years at 33.6%. The study revealed that 20.1% and 11.4% of the respondents were aged above 61 years and below age 25 years respectively. In terms of occupation, majority of the respondents (66.1%) indicated that they were farmers. Those engaged in small scale business and casual laborers were 10.4% and 10.0% respectively. A further 4.2% of the respondents reported to have been engaged with other different occupational roles, while 3.5% of the respondents indicated that they were not engaged in any form of economic activities.

Majority of the respondents in the study area were married in monogamous union at 78.2%. The study established that 12.5% of the respondents were widowed while 5.2% reported to have had orphans in their households. There was a small percentage of respondents (1.7%) who were in polygamous marriage.

TABLE 3
SUMMARY OF DEMOGRAPHIC CHARACTERISTICS

Variable	Category	Frequency	Percentage
Relations to household head	Household head	110	38.1
	Spouse	139	48.1
	Child	29	10
	Parent/guardian	11	3.8
Gender	Female	185	64
	Male	104	36
Education	College	16	5.5
	None	20	6.9
	Primary	163	56.4
	Secondary	86	29.8
	University	4	1.4

Age of respondent	18-25 years	33	11.4
	26-40 years	101	34.9
	41-60 Years	97	33.6
	Above 61 years	58	20.1
Occupation	Students	8	2.8
	Business	30	10.4
	Casual Labourer	29	10
	Farmer	191	66.1
	Teacher	9	3.1
	Not employed	10	3.5
	Other roles	12	4.2
Marital Status	Married (Monogamous)	226	78.2
	Married (Polygamous)	5	1.7
	Separated/Divorced	8	2.8
	Single	14	4.8
	Widowed	36	12.5
Type of Household	Dejure female headed (widow, never married, divorced)	13	4.5
	Female headed	32	11.1
	Male headed	242	83.7
	Polygamous	2	0.7
Presence of an orphan	No	274	94.8
	Yes	15	5.2
Sub-county	Kibwezi East	105	36.3
	Makueni	79	27.4
	Mbooni	105	36.3

3.3 Farmer's perception on climate change in the study area:

3.3.1 Experience of extreme weather conditions:

The study established that 76.8% of the farmers experienced extreme weather conditions, with only 23.2% not experiencing extreme weather conditions. In relation to the agro-ecological zones, more farmers in Kibwezi East and Makueni at 88.6% and 70.9% respectively experienced extreme weather conditions, compared to 69.5% in Mbooni (Table 4). There was significant correlation between the climate change and the agro-ecological zones studied (X^2=13.3, df=2, P<0.01). The Pearson correlation portrayed that the agro-ecological zones studied experienced some form of climate change.

TABLE 4
EXPERIENCE OF EXTREME WEATHER CONDITIONS

	Sub County			Total	Pearson Chi-Square Value	df	Asymptotic Significance (2-sided)
	Kibwezi East	Makueni	Mbooni				
No	12	23	32	67	13.297a	2	0.001
	11.40%	29.10%	30.50%	23.20%			
Yes	93	56	73	222			
	88.60%	70.90%	69.50%	76.80%			
Total	105	79	105	289			

3.4 Livelihood Vulnerability Level:

The livelihood vulnerability index (LVI) for this study used the seven components developed and suggested by Hahn *et al.* (2009). The elements include; climate and natural disasters; access to water; access to food; health; livelihood strategies; social profile; and social networks. The study included other five additional components namely, land, indigenous knowledge, natural resources, housing and production methods and finance and income to assess climate-related risks owing to climate change. The components had several other inherent indicators or sub components, which were selected after review of literature.

Climate variability was measured from secondary data sources using standard deviation of minimum and maximum value of monthly air temperatures as well as monthly precipitation in the last five years. For the vulnerability, the indices were calculated using the adaptive capacity, subtracted from sensitivity and exposure indices. The general indices before standardization are as shown in Table 5.

TABLE 5
GENERAL INDICES FOR THE HUMAN VULNERABILITY INDEX

Sub County	General Index	Kibwezi East	Makueni	Mbooni
Livelihood index	0.173	0.192	0.154	0.168
Water Index	0.575	0.700	0.487	0.533
Food Index	1.168	1.053	1.238	1.231
Health Index	1.196	1.259	1.209	1.123
Social networks index	1.125	1.106	1.142	1.132
Social Demographic Networks Index	2.387	2.571	2.376	2.210
Land Index	2.087	1.937	1.966	2.330
Environmental Resources Index	0.035	0.016	0.035	0.072
Housing production index	1.143	1.227	1.089	1.074
Finance and Income Index	1.434	1.377	1.447	1.481
Natural disasters and climate diversification Index	0.713	0.729	0.741	0.670
Knowledge and Indigenous Knowledge index	1.816	1.761	1.835	1.856

3.4.1 Livelihood Strategies (LS) Index:

Livelihood Strategy index was measured using seven sub-indicators. These included; HHs dependent solely on agriculture as major source; Average agricultural livelihood diversification; HHs not growing horticultural crops like vegetables and fruit trees; HHs not using irrigation; HHs with no non-farm activities; HHs with a member working outside the community/wage labour; and HHs exploiting natural resource during times of extreme events, e.g. charcoal burning.

Livelihood Strategy index = (HHs dependent solely on agriculture as major source + Av. Agricultural livelihood diversification + HHs not growing horticultural crops like vegetables and fruit trees + HHs not using irrigation + HHs with no non-farm activities + HHs with a member working outside the community/wage labour + HHs exploiting natural resource during times of extreme events, e.g. charcoal burning) /7 (the n -number of the weighted components). The resultant weighted index for the livelihood component, and for the three ecological zones is as shown in Table 6.

TABLE 6
LIVELIHOOD STRATEGIES INDEX

Components	General Index	Kibwezi East	Makueni	Mbooni
Mean Index	0.173	0.192	0.154	0.168
Weighted Index (Sq)	0.173	-0.142	0.154	-0.165

3.4.2 Water (W) Index:

Water index was calculated as an average of seven components as shown in Table 7;

Water index = (Av. Distance to water source (Km) + HHs using natural water sources + HHs without constant water supply + HHs harvesting and storing rain water + HHs with piped water from public water systems + Av. Daily water use litres per household + HHs reporting water conflicts) /7.

TABLE 7
WATER INDEX

Components	General Index	Kibwezi East	Makueni	Mbooni
Mean	0.575	0.700	0.000	0.533
Weighted Index (Sq)	-0.758	0.000	0.000	-0.800

The weighted water index for the three ecological zones was -0.758, where it was 0.000 for Kibwezi East and Makueni and -0.800 for Mbooni. This means that the two ecological zones, Kibwezi East and Makueni were extremely vulnerable when it came to water sources.

3.4.3 Food (F) Index:

Food index was calculated using six sub-components as shown. This was shown by the method below;

Food index = (HHs dependent on farm produce for food + HHs dependent on animal product from own source + Av. Crop diversification and crop types grown + HHs who do not save/store their grain crop + HHs without saved seeds for next season + Av. No of months HHs struggle with food shortage)/6 (n-frequency of the variables). The resultant indices for the three regions combined and for each specific ecological zones are as shown in Table 8

TABLE 8
FOOD INDEX

Components	General Index	Kibwezi East	Makueni	Mbooni
Mean	1.168	1.053	1.238	1.231
Weighted Index (Sq)	0.739	0.624	0.438	0.802

3.4.4 Health (H) Index:

Health index was calculated as follows;

Health index = (Av. Distance to health care facility (km) + HHs with a family member with chronic illness + HHs with a family member with illness who missed work or school in the last 1 month + HHs with a family member with illness due to extreme events)/4. The following were the indices (Table 9).

TABLE 9
HEALTH INDEX

Components	General Index	Kibwezi East	Makueni	Mbooni
Mean index	1.196	1.259	1.209	1.123
Weighted Index (Sq)	0.196	0.259	0.209	-0.211

3.4.5 Social Networks (SN) Index:

The social networks index was calculated using the four sub-components as shown;

Social networks (SN) index = (HHs received cash aid in last 12 months + HHs received relief/help due to extreme events + HHs reporting no membership to any organization + HHs not receiving any government aid in the last 12 months)/4. The following were the indices (Table 10).

TABLE 10
SOCIAL NETWORKS INDEX

Components	General Index	Kibwezi East	Makueni	Mbooni
Mean Index	1.125	1.106	1.142	1.132
Weighted Index (Sq)	0.125	-0.894	0.142	-0.201

3.4.6 Social Demographic Profile (SDP) Index:

The social demographic profile (SDP) index was calculated as follows;

Social demographic profile (SDP) index = (Dependency ratio + HHs headed by female (Male head away>6 Months) + HHs headed by child + Av. Household family size + HHs with orphans (Children< 18 years) /4. The following were the indices (Table 11).

TABLE 11
SOCIAL DEMOGRAPHIC INDEX

Components	General Index	Kibwezi East	Makueni	Mbooni
Mean Index	2.387	2.571	2.376	2.210
Weighted Index (Sq)	2.087	2.270	2.076	1.781

3.4.7 Indigenous Knowledge (IK) Index:

Indigenous Knowledge (IK) Index = (HHs head attended no school + HHs head attained /completed primary level + HHs head did not receive training to cope with extreme events + HHs not satisfied with Governments sharing of climate change information + HHs reporting use of indigenous knowledge) /5. The following were the established indices (Table 12).

TABLE 12
INDIGENOUS KNOWLEDGE (IK) INDEX

Components	General Index	Kibwezi East	Makueni	Mbooni
Mean Index	1.816	1.761	1.835	1.856
Weighted Index (Sq)	1.217	1.162	1.237	1.257

3.4.8 Land (L) Index:

Land (L) index = (HHs participation in local government decisions + Av. Land hold size + HHs with small land scale (0.5-1 Ha)) /3. The following were the indices (Table 13).

TABLE 13
LAND INDEX

Components	General Index	Kibwezi East	Makueni	Mbooni
Mean Index	2.087	1.937	1.966	2.330
Weighted Index (Sq)	1.657	1.508	1.537	1.901

3.4.9 Environmental Resources (NR) Index:

Environmental Natural Resources index = (HHs exploiting natural resource for livelihood + HHs using crop residues as source of energy + HHs using traditional jikos for cooking + HHs using LPG cylinders) /4. The following were the indices s calculated (Table 14).

TABLE 14
ENVIRONMENTAL RESOURCES INDEX

Components	General Index	Kibwezi East	Makueni	Mbooni
Mean Index	0.036	0.000	0.035	0.072
Weighted Index (Sq)	0.036	0.000	0.035	0.072

3.4.10 Housing and Production (HP) Index:

Housing and Production Index = (HHs with no means of production + HHs with temporary house + HHs house affected or property during extreme events (Floods)) /3. The following were the indices (Table 15).

TABLE 15
HOUSING PRODUCTION INDEX

Components	General Index	Kibwezi East	Makueni	Mbooni
Mean Index	1.1426	1.227	1.0893	1.0741
Weighted Index (Sq)	1.0326	1.062	0.9793	0.9091

3.4.11 Finance and Income (FI) Index:

The finance and income (FI) index was as follows;

Finance and income (FI) index = (HHs with net annual income lower than Ksh 200,000 + HHs borrowing money in the last 1 month + HHs lending money in the last 1 month + HHs with no income during extreme events + HHs with no access to financial institutions) /5. The following was the indices (Table 16).

TABLE 16
FINANCE AND INCOME (FI) INDEX

Components	General Index	Kibwezi East	Makueni	Mbooni
Mean Index	1.434	1.377	1.447	1.481
Weighted Index (Sq)	0.682	0.377	0.117	0.729

3.4.12 Natural Disasters and Climate Diversity (NDCV):

The following was the natural disasters and climate diversity index;

natural disasters and climate diversity index = (Av. No. of extreme events drought and floods in the last 5 years + HHs reporting crop damage due to extreme events in last 5 years + HHs not receiving Early warning preceding extreme events + HHs reporting crop failure due to extreme events in last 5 years + HHs with death or injury as a result of extreme events)/5. The following were the indices (Table 17).

TABLE 17
NATURAL DISASTERS AND CLIMATE DIVERSITY INDEX

Components	General Index	Kibwezi East	Makueni	Mbooni
Mean Index	0.713	0.729	0.741	0.670
Weighted Index (Sq)	-0.287	-0.271	-0.259	-0.330

Livelihood index was calculated as a general from all the other indices as presented on Table 7.1, where the general index along with those for each of the agro-ecological zones was presented. The summary of the LVI - IPCC index was presented on Table 18.

TABLE 18
LVI INDEX

Components	General Index	Kibwezi East	Makueni	Mbooni
Livelihood Index	0.575	0.496	0.555	0.479

The livelihood vulnerability index for the Makueni County smallholder farmers was 0.574, while for the three ecological zones were Kibwezi East at 0.496, Makueni was 0.555 while for Mbooni was 0.479.

3.4.13 Vulnerability Index:

From the literature review, vulnerability was calculated as follows;

Vulnerability = (Adaptive capacity) – (Sensitivity + Exposure)

The adaptive capacity was framed on Socio-Demographic Profile, Livelihood Strategy and Social Networks. Exposure was incorporated into the framework of Natural Disaster and Climate Variability and Sensitivity on Food, Water and Health. The general adaptive index for the three agro-ecological zones was 1.229, while for Kibwezi East was 1.289, Makueni was 1.224 and for Mbooni at 1.170. The index was shown on Table 7.15.

The adaptive capacity was calculated as follows; (Adaptive capacity = (Socio-Demographic Profile, + Livelihood Strategy + Social Networks)/3)

TABLE 19
ADAPTIVE CAPACITY INDEX

Adaptive capacity	General Index	Kibwezi East	Makueni	Mbooni
Socio-Demographic Profile	2.387	2.571	2.376	2.210
Livelihood Strategy	0.173	0.192	0.154	0.168
Social Networks	1.125	1.106	1.142	1.132
Index	1.229	1.289	1.224	1.170

Exposure for this study was measured by finding the average of natural disaster and climate variability as shown on Table 7.16. Further, the general exposure index is calculated, along with the index for the three agro-ecological zones is presented on Table 20.

Exposure = (Natural Disaster + Climate Variability)/2

TABLE 20
EXPOSURE INDEX

Exposure	General Index	Kibwezi East	Makueni	Mbooni
Natural Disaster	0.713	0.729	0.741	0.670
Climate Variability	1.242	1.270	1.415	1.130
Index	0.651	0.666	0.719	0.600

Further, the researcher calculated the general sensitivity index for the study area, and one each for the three agro-ecological areas. The sensitivity index was calculated by combining three components, food, water and health as shown on Table 21 below.

Sensitivity = (Food +Water + Health)/3

TABLE 21
SENSITIVITY INDEX

Sensitivity	General Index	Kibwezi East	Makueni	Mbooni
Food	1.168	1.053	1.238	1.231
Water	0.575	0.700	0.000	0.533
Health	1.196	1.259	1.209	1.123
Index	0.980	1.004	0.816	0.962

This objective sought to find and establish the vulnerability index for the three agro-ecological zones. The vulnerability was calculated using adaptive capacity, minus the sensitivity and exposure (Vulnerability = (Adaptive capacity) – (Sensitivity + Exposure)). Vulnerability levels for the entire study area, along each for the agro-ecological zones as shown on Table 22.

TABLE 22
VULNERABILITY LEVELS

Components	General vulnerability Index	Kibwezi East	Makueni	Mbooni
Vulnerability levels	-0.464	-0.443	-0.332	-0.462

The study established that the vulnerability index for the three agro-ecological zones combined was -0.464. In respect to the three areas, Mbooni had the highest vulnerability index at 0.462, followed by Kibwezi East at 0.443 and Makueni at 0.332

IV. DISCUSSIONS

Based on the findings from the current study, the three ecological zones had indices less than 0.4 (general 0.17, Kibwezi East at 0.14, Makueni at 0.15 and Mbooni 0.16) showing that the households had high livelihood strategies. This meant that there were many households depending solely agriculture as a major source of livelihood, and there was low agricultural livelihood diversification, and many households not growing horticultural crops like vegetable and fruit trees. The indices means that many of the households had limited livelihood strategies. The findings relate to findings by Moret (2014) on livelihood strategies index who showed ranges for livelihood strategies (as depicted by the changes in household income and expenditure patterns) ranged from low (>0.6), moderate (0.4 to 0.6) and high (<0.4).

Based on the findings from the current study, the three ecological zones had indices less than 0.4 (general 0.17, Kibwezi East at 0.14, Makueni at 0.15 and Mbooni 0.16), showing that the households had high livelihood strategies. This meant that many households were depending solely on agriculture as a major source of livelihood, and there was low agricultural livelihood diversification, and many households did not grow horticultural crops like vegetables and fruit trees. The indices mean that many of the households had limited livelihood strategies. The findings relate to findings by Moret (2014) on the livelihood strategies index, who showed ranges for livelihood strategies (as depicted by the changes in household income and expenditure patterns) ranged from low (>0.6), moderate (0.4 to 0.6) and high (<0.4).

Climate variability was measured from secondary data sources using the standard deviation of minimum and maximum values of monthly air temperatures as well as monthly precipitation in the last five years. For the vulnerability, the indices were calculated using the adaptive capacity, subtracted from sensitivity and exposure indices. A study by Salman et al. (2022) examined the livelihood vulnerability of smallholder farmers to climate change using a comparative analysis based on irrigation access in South Sulawesi, Indonesia. The study aimed to evaluate the vulnerability of the livelihood system among rice-growing farmers in the Bettu River irrigation area. The study classified the area into two zones based on the distance from the main irrigation canal, namely the upstream and downstream areas. The livelihood vulnerability index (LVI) approach was applied through the selection of socio-demographic and geographic indicators which impacted farmer households.

Empirical results from the study indicated that farmers in the downstream area were more vulnerable to climate change than those in the upstream area. Major components that used the LVI were livelihood strategy, health, water, food, and natural disasters and climate variability. In short, the study concluded and recommended that the sub-components of agricultural livelihood diversification, consistent supply of water for farming activities, and drought mitigation strategies were valuable in the downstream area. Farmers who practice irrigation in the upstream area are vulnerable to socio-demographic profile and social network components.

Compared to findings in this study, the study by Salman et al. (2022) recommends that concerned authorities should now prioritize farmers in the downstream area as a way to develop resilience strategies, specifically by improving or increasing irrigation infrastructure and the number of available reservoirs and drilling holes to control erosion. Also, farmers can increase their adaptive capacity through diversification of agricultural livelihood systems. Governments in collaboration with donor agencies should provide farmers with training on the development of home food industries for poor farmers and households that are vulnerable and were affected by climate change disasters.

In terms of vulnerability to the water and food index, Makueni and Kibwezi East were found to be completely vulnerable to water. Water index was measured in terms of distance and time spent to access natural water sources. Health index was calculated using distance covered to access the nearest public or private health facility and the number of family members who have had a health-related complication for the last month (Tables 7 and 8).

In this study, the mean social networks index was 0.1254, which showed that the households in the three agro-ecological zones were highly vulnerable. Those most vulnerable were in Kibwezi East (-0.8939) followed by those in Mbooni at -0.2011. In comparison, households in Makueni were better off than the other two areas, but still fell under the highly vulnerable households. The study by Moret (2014) on the social networks index showed that scores above 0.6 (>0.6 are low, while 0.4 to 0.5 are moderately exposed, and scores below 0.4 are highly exposed and vulnerable. Further, the study by Moret (2014) gives a range of vulnerability score which reflects the findings in this study.

The current study's findings on the Livelihood Vulnerability Index (LVI) closely align with the results from Madhuri et al. (2014), who applied a similar index-based approach in Bihar to capture multi-dimensional vulnerability. Both studies identify water, food security, and health components as major drivers of vulnerability, highlighting the dependence of rural households on climate-sensitive resources. However, while Madhuri et al. found socio-demographic factors (such as high dependency ratios and low education levels) as dominant contributors, the present study reports land access and indigenous knowledge as critical, with indices above 1.8 for IK and 2.0 for land. This difference can be attributed to the contextual variations, where indigenous knowledge systems remain strong in the Kenyan setting, whereas in Bihar, institutional support and infrastructure gaps are more influential in determining vulnerability levels.

The findings also share similarities with Saha et al. (2024), who assessed the vulnerability of coastal communities to climate change using an index-based approach. Like the current study, Saha et al. emphasize the importance of water access and food security as sensitive components driving vulnerability. In both cases, water indices indicated significant exposure, with Kibwezi East and Makueni showing extreme vulnerability due to long distances to water sources, echoing Saha et al.'s findings in coastal zones with saline intrusion challenges. However, the present study diverges by highlighting social demographic profiles and indigenous knowledge as unique elements contributing to adaptive capacity, whereas Saha et al. focused more on income diversification and institutional support. This suggests that inland agro-ecological systems like Makueni's require a different adaptation lens compared to coastal ecosystems.

Further, Quandt (2018) proposes the Household Livelihood Resilience Approach (HLRA), which measures resilience rather than just vulnerability, stressing household assets, adaptive capacity, and coping strategies. When compared to the current findings, the adaptive capacity index (1.229) for Makueni County indicates moderate resilience; however, the strong negative vulnerability score (-0.464) suggests that sensitivity (0.980) and exposure (0.651) outweigh adaptive mechanisms. Quandt argues that resilience improves with social networks and livelihood diversification, yet in this study, the social networks index remained low (0.125) and the livelihood strategy index (0.17) was below the resilience threshold, reflecting limited non-farm activities and weak institutional linkages. This contrast illustrates that while the HLRA framework advocates for asset-based resilience building, regions with poor water and income diversification remain structurally vulnerable despite some coping strategies.

Additionally, Rubiyanto and Hirota (2021) emphasize livelihood diversification as a crucial adaptation measure for reducing vulnerability in Southeast Asia. Their review underscores that households adopting multiple income sources exhibit lower exposure to climate shocks. In contrast, the current study reveals that most households in Kibwezi East, Makueni, and Mbooni rely primarily on agriculture, with limited non-farm opportunities, leading to a high vulnerability score in livelihood strategies (below 0.4). Similarly, Sadekin et al. (2021) highlight that dependence on a single resource (like fisheries) amplifies vulnerability in small-scale systems. Both findings align with the Kenyan context, where over-reliance on rain-fed agriculture exacerbates risk, reinforcing the need for policy-driven livelihood diversification programs. These cross-comparisons indicate that while index-based assessments consistently identify water, food, and income as critical factors, regional variations in socio-cultural practices and economic structures shape the intensity and drivers of vulnerability.

V. CONCLUSIONS AND RECOMMENDATIONS

The study focused on livelihood levels for smallholder farmers in the three agro-ecological zones in Makueni, Kibwezi East and Mbooni. The livelihood levels were measured by livelihood rates/rates and compared to the established standards. The human variability index was measured by 12 components, where the results were as follows; livelihood index was 0.173, water index 0.575, and food index was 1.168. Further, health index was 1.196 and social networks index was 1.125. Further, the social demographic networks index was 2.387, while land index was 2.087a, and environmental resources index (0.035). The other indices were; housing production index (1.143), finance and Income index (1.434), natural disasters and climate diversification index (0.713), knowledge and Indigenous Knowledge index (1.816). The general adaptive index for the three agro-ecological zones was 1.229, where Kibwezi East was 1.289, Makueni was 1.224 and for Mbooni at 1.170. The study established that the overall vulnerability index for the three agro-ecological zones combined was 0.464. In respect to the three areas, Mbooni had the highest vulnerability index at 0.462, followed by Kibwezi East at 0.443 and Makueni at 0.332. The findings showed that the respondents in the three agro-ecological zones had few livelihood options and strategies, often depending on agriculture which was not sustainable due to effects of climate change.

The following were the recommendations:

i. There is need for the local actors to improve on the components that contribute to high vulnerability levels in the study area.

ii. There is need to do more studies on vulnerability indices for Makueni County, and compare different sub-counties, as well as comparing it with the national vulnerability levels

REFERENCES

[1] Asfaw, A., Bantider, A., Simane, B., and Hassen, A. (2021). *Smallholder farmers' livelihood vulnerability to climate change-induced hazards: agroecology-based comparative analysis in Northcentral Ethiopia* (Woleka Sub-basin) https://doi.org/10.1016/j.heliyon.2021.e06761

[2] Can, N.D., Tu, V.H., and Hoanh, C.T., (2013). *Application of Livelihood Vulnerability Index to Assess Risks from Flood Vulnerability and Climate Variability*—A Case Study in the Mekong Delta of Vietnam, Journal of Environmental Science and Engineering A 2, 476-486.

[3] Donattia, C.I., Harvey C.A, Rodriguez, R.M., Vignolab, R. and Manuel, C.R. (2019). *Vulnerability of Smallholder farmers to Climate Change in Central America and Mexico: current knowledge and research gaps, Climate and Development,* Vol. 11, No. 3, 264–286, https://doi.org/10.1080/17565529.2018.1442796

[4] Etwire, P.M., Al-Hassan, R.M., John K. M. Kuwornu, J.K.M., and Owusu, Y.O., (2013). *Application of Livelihood Vulnerability Index in Assessing Vulnerability to Climate Change and Variability in Northern Ghana, Journal of Environment and Earth Science* ,Vol. 3, No.2.

[5] FAO, (2010). *Analysis of Climate Change and Vulnerability Risks in The Small-scale holder Sector: Case studies of Laikipia and Narok Districts Representing Major Agro-ecological Zones in Kenya.*

[6] GOK (2018). *National Climate Change Action Plan (Kenya): 2018-2022. Volume 3: Mitigation Technical Analysis Report.* Nairobi: Ministry of Environment and Forestry.

[7] Hahn, M.B., Riederer, A.M., and Foster, S.O., (2009). *The Livelihood Vulnerability Index: A pragmatic approach to assessing risks from climate variability and change—A case study in Mozambique, Global Environmental Change :* Human and Policy Dimensions. 19 (1): 74-88 http://dx.doi.org/10.1016/j.gloenvcha.2008.11.002.

[8] Harvey C.A , Rodriguez, M.S., Rodriguez R.M, Viguera, B., Guadarrama, A.C.,Vignola, R. and Alpizar, F. (2018). *Climate Change Impacts and Adaptation among Smallholder Farmers in Central America, Agriculture & Food Security.* https://doi.org/10.1186/s40066-018-0209-x

[9] Intergovernmental Panel on Climate Change, (2021). *Emission scenarios*. Cambridge University Press.

[10] KEPSA, (2014). *Climate Change and the Agriculture Sector,* Nairobi Kenya

[11] Maluki, J. M., Kimiti, J. M., Nguluu, S., & Musyoki, J. K. (2016). Adoption levels of agroforestry tree types and practices by smallholders in the semi-arid areas of Kenya: A case of Makueni County. *Journal of Agricultural Extension and Rural Development*, *8*(9), 187-196.

[12] Minh, D.D., Lebailly, P., Hao, N. D., Burny, P., Hop, T.M., (2019). *The Dynamics of Livelihood Vulnerability Index at Farm Household Level: An Empirical Analysis of the Coastal Sandy Zone in Thua Thien Hue Province, Vietnam.* International Journal of Economics and Financial Issues, 2019, 9(5), 77-89. DOI: https://doi.org/10.32479/ijefi.8250.

[13] Mogelgaard, K., A. Dinshaw, N. Ginoya, M. Gutiérrez, P. Preethan, and J. Waslander. 2018. *From Planning to Action: Mainstreaming Climate Change Adaptation into Development*. Working Paper. Washington, DC: World Resources Institute. https://www.wri.org/publication/climate-planning-to-action.

[14] Ochieng, J., Kirimi, L., Mathenge, M. (2016). *Effects of climate variability and change on agricultural production:The case of small scale farmers in Kenya*. NJAS - Wageningen Journal of Life Sciences http://dx.doi.org/10.1016/j.njas.2016.03.005

[15] Salman, D., Yassi, A., & Demmallino, E. B. (2022). Livelihood vulnerability of smallholder farmers to climate change: A comparative analysis based on irrigation access in South Sulawesi, Indonesia. *Regional Sustainability*, *3*(3), 244-253.

[16] Simotwo, H K., Mikalitsa, S. M. and Wambua, B.N. (2018). *Climate change adaptive capacity and smallholder farming in Trans-Mara East sub-County, Kenya.* Geoenvironmental Disasters 5:5 https://doi.org/10.1186/s40677-018-0096-2.

[17] Stockholm Institute of Environment (2009). *The Economics of Climate Change in Kenya*: Final Report Submitted in Advance of COP 15.

[18] United Nations University (2015. *Livelihoods Resilience in a Changing World-6 Global Policy Recommendations for a Sustainable Future*. UNU-EHS Publication Series No.22.

[19] Ylva N., Mattias J, Emmeline L. A, Johanna, W., and Ingrid, O. (2020). *Smallholders' Awareness of Adaptation and Coping Measures to Deal with Rainfall Variability in Western Kenya, Agroecology and Sustainable Food Systems* VOL. 44, NO. 10, 1280–1308 https://doi.org/10.1080/21683565.2020.1782305.

In-Vitro evaluation of phytoextracts against *Colletotrichum gloeosporioides* caused anthracnose disease of custard apple (*Annona squamosa* L.)

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Abstract— *The Custard apple or sugar apple (Annona sqmosa L.) is one of India's oldest dry land fruit crop belonging to family Annonaceae and genus Annona. The extract of ten plants part was evaluated against leaf spots by poisoned food technique. Among them, extract of lantana leaves (Lantana camera L.) (81.91%) was proved excellent in inhibiting mycelial growth of the pathogen. Next best in order of merit was bougainvillea (Bougainvillea spectabilis Willd) leaves extract (58.60%), neem (Azadirachta indica Juss). leaves extracts (58.01%), subabul (Leucaena leucocephala Lam) leaves extract (57.68%), garlic (Allium sativum L.) clove extracts (55.20), ashoka (Polyanthia longifolia Sonn.) leaves extract (54.99%) and Simarouba (Simarouba glauca DC) leaves extract (54.78%).*

Keywords*— *In vitro, Colletotrichum gloeosporioides, Custard apple, anthracnose.

I. INTRODUCTION

Custard apple (*Annona squamosa* L.) is commercially important fruit crop of tropical and sub-tropical regions. This fruit is sometimes also considered as "poor man's rich food" in the arid zones of India and require dry climate with mild winter. The genus name, *Annona* is from the Latin word 'anon', meaning 'yearly produce', referring to the production of fruits of the various species in this genus. Custard apple belong to family *Annonaceae* having 2n=14 and 16 chromosomes and is one of the finest fruits gifted to India by tropical America. Custard apple is commonly cultivated in Mexico, Philippines, New guinea, Malaysia, India and South America contries in the world. In India, it is found wildly and cultivated, especially in Andhra Pradesh, Punjab, Rajastan, Uttar Pradesh, Madhya Pradesh, Bihar, West Bengal, Assam, Tamil nadu. During 2021-22 (Anon, 2022), custard apple was cultivated over 47 million hectares with an annual production of 402 MT in India. Among the various diseases, fungal diseases play an important role to severe loss of custard apple production. Major fungal diseases are leaf and fruit spot (*Colletotrichum gloeosporioides),* alternaria leaf spot (*Alternaria spp.),* cylindrocladium leaf spot (*Cylindrocladium colhounii* and *Cylindrocladium scoparium*), botryodiplodia rot *(Botryodiplodia theobromae*), black canker *(Phomopsis anonacearum*) and gliocladium rot (*Gliocladium roseum*) (Shamsi and Hosen, 2016).

II. MATERIAL AND METHODS

In recent years, many phyto-extracts are being used as fungi toxicant for the management of various plant diseases. The leaves extracts of the Neem (*Azadirachta indica* Juss), Ashoka (*Polyanthia longifolia* Sonn), Nilgiri (*Eucalyptus globulus* Labill), Ardusi *(Adhatoda vasica* Ness.) Lantana (*Lantana camera* L.), Simarouba (*Simarouba glauca* DC), Subabul (*Leucaena leucocephala* Lam.), Bougainvillea (*Bougainvillea spectabilis* Willd.), Garlic (*Allium sativum* L.), Onion (*Allium cepa* L.) were evaluated *in vitro* against *C. gloeosporioides* at 10%,20% and 30% concentrations through poisoned food technique.

The freshly collected plant materials from each plant species were washed thoroughly with tap water and then finally with sterilized distilled water and finally sterilized with 90 per cent methanol and air dried. Weighted plant parts were crushed in electrically operated mixture and grinder using 1:1 w/v amount of sterile distilled water and acetone for 100g of bulb and leaves separately (Singh and Majumdar,2001). The extract was homogenized for five minutes and filtered through two layer of sterilized muslin cloth and then the filtrate was centrifuged at 5000 rpm for 15 minutes. The clean supernatant was collected and was considered as cent per cent concentration (standard solution). This formed the standard plant extract solution (100 %). Phyto-extracts were tested for growth inhibition of the fungus by employing poisoned food technique.

For evaluation of antifungal activities of the plant extracts, desired concentrations (10, 20 and 30%) were obtained by adding appropriate amount of standard solution of plant extracts in 100ml PDA medium in conical flasks. Then 20 ml PDA mixed with such extracts were poured in sterilized Peri plates. A five mm disc of seven days old culture of the pathogen was cut by means of a sterilized cork borer and placed at the centre of the Petri plate. The plates were incubated at 27 ± 2^oC. The medium without incorporating the plant extract was serve as control. Observation on radial growth of fungus was measured by averaging two diameter of colony at right to one another when the control treatment with pathogen reached full growth. Three plates were maintained for each treatment. The per cent growth inhibition of the fungus in each treatment in comparison with control was calculated by the following equation (Bliss, 1934).

$$\text{PGI} = \frac{C-T}{C} \times 100 \qquad (1)$$

Where,

PGI = Per cent growth inhibition

C = Average mycelial growth in control (mm)

T = Average mycelial growth in treatment

III. RESULTS AND DISCUSSION

The plant extracts inhibited the mycelial growth of *C. gloeosporioides* at three different concentrations (10%,20% and 30%) that differed significantly. Among the ten plant extracts, maximum of mycellial growth inhibition (81.91%) was recorded in lantana leaves extract which was significantly superior over other extracts. Next best in order of merit was leaves extract of bougainvillea (58.60%) followed by leaves extract of neem (58.01%) were found on par in mycelial growth inhibition of the pathogen.

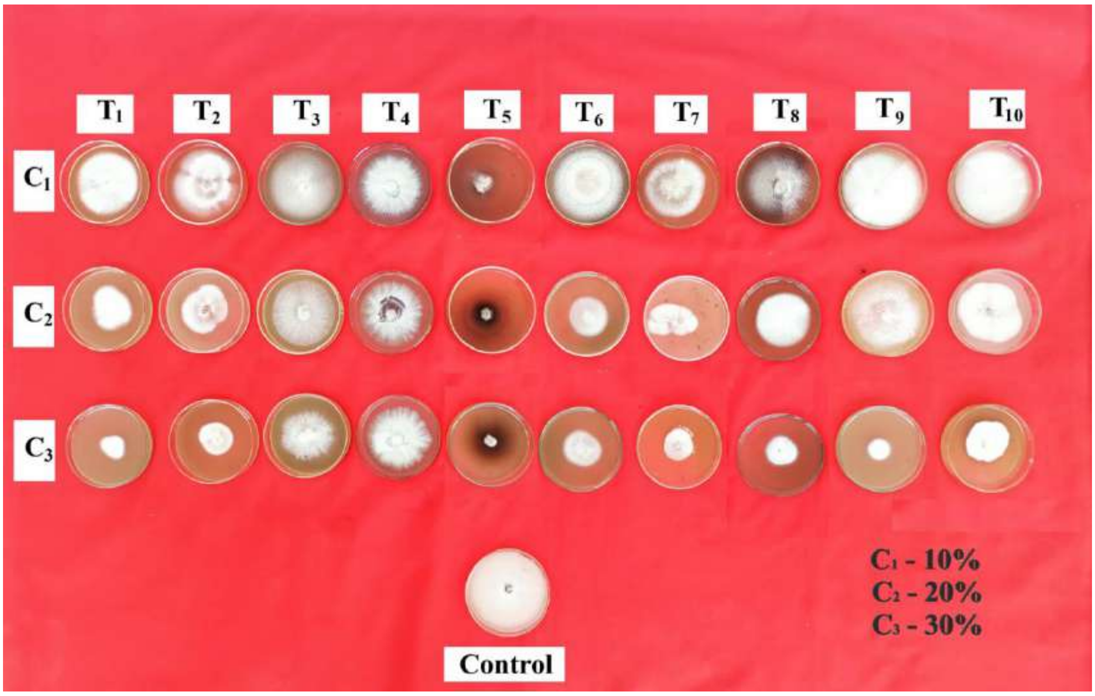
At 30% concentration of plant extracts of maximum of mycellial growth inhibition (84.43%) inhibition of mycellial growth was recorded in lantana leaves extract which was significantly superior over other extracts. Next best in order of merit was leaves extract of bougainvillea (68.35%) followed by leaves extract of neem (66.27%). At 20% concentration of plant extracts of maximum of mycellial growth inhibition (81.64%) inhibition of mycellial growth was recorded in lantana leaves extract which was significantly superior over other extracts. Next best in order of merit was leaves extract of bougainvillea (57.07%). At 10% concentration, mycelial growth inhibition was 45.90 per cent garlic cloves extracts. Overall the maximum per cent inhibition was found in lantana leaves extracts (81.91%) while the least was found in ardusi leaves extracts (48.24%).

Study revealed that, most of the plant extracts showed fungi-static nature at higher concentration (30%). All the plant extracts showed ≥ 58% inhibition of mycelial growth, maximum was found in in lantana leaves extract (81.91%) while least inhibition of mycelial growth was noticed in bougainvillea leaves extract (58.60%). At 20 %concentration, two plant extracts namely lantana leaves extract, bougainvillea leaves extract showed more than 60% inhibition of mycelial growth. Similar effect of the test botanicals/phyto-extracts against *C. gloeosporioides* were reported to cause significant mycelial growth inhibition of *C. gloeosporioides*, earlier by several workers Anteneh *et al*. (2013) studied the antifungal activities of nineteen plant extracts against papaya anthracnose caused by *Colletotrichum gloeosporioides*. They found highest inhibition with ethyl acetate extracts of Lantana camara and showed strong activity against *C. gloeosporioides*. Ramani *et al*. (2015) revealed that the lantana leaves extract at 10 per cent solvent was effective for growth inhibition of *C. gloeosporioides.*

TABLE 1
EFFECT OF PHYTOEXTRACTS ON MYCELIAL GROWTH INHIBITION OF *COLLETOTRICHUM GLOEOSPORIOIDES*

Tr. No.	Phytoextract	Plant part used	Per cent Growth inhibition over control			Mean
			Concentration%			
			10	20	30	
T1	Neem	Leaves	47.81 (54.44)**	59.96 (74.44)	66.27 (83.33)	58.01 (70.7)**
T2	Ashoka	Leaves	48.45 (55.55)	57.31 (70.37)	59.21 (73.33)	54.99 (66.41)
T3	Nilgiri	Leaves	47.39 (53.7)	50.17 (58.51)	59.93 (74.44)	52.50 (62.21)
T4	Ardusi	Leaves	46.75 (52.59)	48.45 (55.55)	49.53 (57.40)	48.24 (55.18)
T5	Lantana	Leaves	79.67 (96.29)	81.64 (97.37)	84.43 (98.51)	81.91 (97.39)
T6	Simarouba	Leaves	47.81 (54.44)	57.07 (69.99)	59.45 (73.70)	54.78 (66.04)
T7	Subabul	Leaves	50.82 (59.62)	57.07 (69.99)	65.14 (81.85)	57.68 (70.49)
T8	Bougainvillea	Leaves	50.39 (58.88)	57.07 (69.99)	68.35 (85.92)	58.60 (71.06)
T9	Garlic	Clove	45.90 (51.11)	49.74 (57.77)	69.95 (87.77)	55.20 (65.49)
T10	Onion	Bulb	46.54 (52.22)	52.57 (62.41)	62.19 (77.77)	53.76 (64.19)
T11	Control	-	4.5 (0.00)	4.5 (0.00)	4.5 (0.00)	4.5 (0.00)
Mean			47.02 (53.53)	52.44 (62.41)	59.11 (72.18)	
			Treatment (T)	Concentration (C)		TxC
S.Em.±			0.327	0.171		0.566
C.D. at 5%			0.923	0.482		1.599
C.V.%			1.86			

*****Figures in parentheses are original values and outside are arc-sine transformed values***



PLATES 1: *In vitro* effect of phyto-extracts on growth and inhibition of *C. gloeosporioides*

IV. CONCLUSION

The present study demonstrated that phyto-extracts possess considerable antifungal potential against Colletotrichum gloeosporioides, the causal agent of leaf and fruit spot in custard apple. Among the ten plant extracts evaluated, Lantana camara leaves extract consistently exhibited the highest level of mycelial growth inhibition across all concentrations, recording up to 84.43% inhibition at 30% concentration. Bougainvillea and neem leaf extracts were found next in efficacy, while extracts such as ardusi showed comparatively lower activity.

The findings clearly indicate that certain botanicals, particularly Lantana camara, can serve as effective, eco-friendly alternatives to synthetic fungicides for the management of anthracnose in custard apple. Since the antifungal activity of these extracts increased with concentration, their role in integrated disease management appears promising. However, further investigations under field conditions, along with standardization of formulations and application methods, are required before their large-scale use in commercial custard apple cultivation.

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REFERENCES

[1] Anonymous (2022). Area and production of pomegranate fruit in India. *National horticulture mission online sources*.

[2] Anteneh, A.; Amare, A. and Kebede, W. (2013). Evaluation of antifungal activity of plant extracts against papaya anthracnose (*Colletotrichum gloeosporioides*). *Journal of Plant Pathology and Microbiology*. **4**: 10.

[3] Bliss, C. L. (1934). The methods of probits analysis. *Science*. **79**: 38.

[4] Ramani, V. N.; Davara, D. K.; Anadani, V. P. and Detroja, A. M. (2015). Evaluation of fungicides, botanicals and biocontrol agents against banana anthracnose disease under *in vitro* condition. *International Journal of Plant Protection*. **8** (2): 228-233.

[5] Shamsi, S. and Hosen, S. (2016). Mycoflora associated with fruit rot of custard apple (*Annona squamosa* L.). *Bangladesh Journal of Scientific Research*. **29**(2): 173-176.

[6] Singh, J. and Majumdar, V. L. (2001). Efficacy of plant extracts against *Alternaria alternata* - the incitant of fruit rot of pomegranate. *Journal of Mycology and Plant Pathology*. **31**(3): 346-349.

Socio-Economic Profile, Disposal Pattern, and Production Constraints of Finger Millet Farmers in Almora District of Uttarakhand

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Abstract— *The study examines the socio-economic profile, disposal pattern, and production constraints of finger millet farmers in Almora district, Uttarakhand, the state's leading producer. Three development blocks were purposively selected, with 90 farmers chosen through multi-stage random sampling. Primary data for 2022–23 were collected via structured interviews, and secondary data on area and production (2008–09 to 2022–23) were sourced from official records. Descriptive statistics were used to analyze socio-economic variables, while Garret's ranking technique identified key production and marketing constraints. Results revealed that cultivation is dominated by middle-aged farmers (35–55 years), with moderate literacy, large family sizes, and small, largely rainfed holdings. Livestock, especially goats and buffaloes, form a vital component of the farming system, with major investment in cattle sheds. On-farm income accounted for the bulk of household earnings. Constraints included labour scarcity, low productivity, inadequate irrigation, and market access issues, underscoring the need for targeted interventions to sustain and enhance finger millet cultivation.*

Keywords— Finger millet, Almora district, socio-economic profile, disposal pattern, production constraints, hill agriculture.

I. INTRODUCTION

Finger millet (*Eleusine coracana*), locally known as *mandua*, is one of the most important traditional cereal crops cultivated in the hilly regions of Uttarakhand. It plays a crucial role in household food security, livestock feeding, and income generation, especially in rainfed and resource-constrained areas (Negi et al., 2017). Owing to its high nutritional value, particularly in calcium, dietary fiber, and essential amino acids, finger millet has been increasingly recognized as a "nutri-cereal" and is being promoted under various government programmes like the National Food Security Mission (NFSM) and Millet Mission (GoI, 2022).

In Uttarakhand, Almora district stands out for its significant area under finger millet cultivation due to its suitability to the mid- and high-altitude conditions and its adaptability to low-input farming systems (Bhatt et al., 2018). The crop not only sustains the livelihoods of marginal and smallholder farmers but also forms an integral part of traditional food systems and cultural practices. However, in recent decades, finger millet cultivation in the region has witnessed a declining trend due to factors like changing dietary preferences, rural outmigration, low market prices, and inadequate marketing infrastructure (Bisht et al., 2021).

Disposal patterns of finger millet vary considerably across households, with a large share retained for home consumption, some used for livestock feed, and the rest sold in local markets. The decision on disposal is influenced by socio-economic characteristics such as farm size, income, education, and household food requirements (Singh et al., 2019). In addition, farmers face numerous constraints in production and disposal, including low productivity, high labour requirements, poor access to improved seed varieties, and lack of organized marketing channels (Joshi & Negi, 2016).

Given this backdrop, a systematic assessment of farmers' socio-economic characteristics, disposal patterns, and constraints is essential to formulate strategies that can enhance production, market linkages, and farmer income, thereby revitalizing finger millet cultivation in Almora district.

Problem Statement

Finger millet cultivation in Almora district, despite its historical and nutritional importance, is facing multiple challenges threatening its sustainability. Smallholder farmers in the region rely heavily on finger millet for household consumption and as a supplementary source of income. However, productivity levels remain low due to factors such as limited adoption of improved agronomic practices, lack of access to quality seeds, high labour dependency, and vulnerability to climatic variability (Negi et al., 2017; Bhatt et al., 2018).

Market-related issues further exacerbate the situation. The disposal of finger millet is often restricted to local markets or barter systems, yielding minimal returns to farmers. The absence of organized procurement, poor price realization, and lack of value addition facilities reduce the incentive to expand cultivation (Bisht et al., 2021). Moreover, the changing socio-economic landscape, including migration and dietary shifts towards wheat and rice, has led to a decline in both area and production of the crop (Singh et al., 2019).

While several government initiatives under the Millet Mission aim to promote millets, there is limited empirical evidence from Almora district assessing the socio-economic profile of farmers, their disposal practices, and the constraints they face. Without such localized data, policy and extension interventions may not address the actual bottlenecks in production and marketing. This study, therefore, seeks to fill this gap by providing an in-depth analysis, which will serve as a basis for targeted interventions to revive finger millet cultivation in the region.

II. METHODOLOGY

The study was conducted in Almora district, Uttarakhand, which records the highest area and production of finger millet in the state. The sampling framework ensured a representative selection of blocks, villages, and farmers. Out of eleven development blocks, three were purposively chosen based on area under finger millet: Dhauladevi, Hawalbagh Lamgarah. From each block, two villages were randomly chosen in consultation with block officials. Farmers cultivating finger millet on at least one-fourth of their land during kharif 2022–23 were listed, and 15 farmers per village were randomly selected using a random number table, giving a total sample of 90 farmers.

Primary data was collected through personal interviews using a structured schedule, covering family profile (size, education, occupation, income), landholding, livestock, assets, inputs used, production, disposal pattern, and marketing details for 2022–23. **Secondary data** on area and production (2008–09 to 2022–23) was gathered from government records, reports, journals, and other publications.

Descriptive statistics (averages, percentages) were used to analyze the **socio-economic characteristics** of the respondents-farmers such as age, education, family size, landholding, cropping pattern, income, livestock, and resource availability. **In order to examine the disposal pattern of finger millet d**escriptive analysis captured total production, quantities retained (consumption, seed) and marketed, along with timing of sale, price, and selling costs. The constraints faced in production and marketing of **finger millet** were identified with expert input. The constraints experienced by the farmers were investigated in order to examine the limitations on finger millet production and marketing. Furthermore, in consultation with experts a set of possible constraints were identified. The respondent-farmers were asked to rank the identified constraints according to their order of severity. On the basis of the given ranks each constraint's percent position was found out using Garret's ranking technique.

$$\text{Percent Position} = \frac{(R_{ij} - 0.5)}{N_j} \times 100 \quad (1)$$

Where,

R_{ij} is the rank given for the i^{th} term by the j^{th} individual

N_j is the number of items ranked by the j^{th} individual

Percent position was converted into garret's score using the table given by Garret and Woodworth (1969). For each factor the scores of individual respondent were summed up and divided by the total number of respondents from whom scores were gathered. The mean scores for all the factors were arranged in descending order and thus rank were assigned to the constraints.

III. RESULTS AND DISCUSSION

The socio-economic characteristics of finger millet growing farmers in Almora district have been assessed and discussed under following heads;

3.1 Age-wise distribution of finger millet growing farmers:

Age is a key factor in assessing the socio-economic status of farmers, as it directly influences their experience, decision-making ability, technology adoption, and overall understanding of agricultural practices. Younger farmers are generally more open to adopting modern technologies and methods, while older farmers may prefer traditional techniques. This generational difference can affect how agricultural innovations are embraced and implemented.

The age profile of finger millet farmers in Almora district is presented in Table 1. The results indicate that the majority of respondents (48.88%) belonged to the 35–55 years age group, with a mean age of 41.02 years. This was followed by younger farmers below 35 years (33.33%) with a mean age of 30.40 years, while farmers aged 55 years and above accounted for 17.78% with a mean age of 61.06 years.

At the block level, the 35–55 years group predominated in all three blocks, accounting for 46.66% in Lamgarah, 43.33% in Dhauladevi, and 56.66% in Hawalbagh. The proportion of younger farmers (<35 years) was relatively higher in Dhauladevi (40.00%) compared to Lamgarah (36.66%) and Hawalbagh (23.33%). The highest share of older farmers (≥55 years) was observed in Hawalbagh (20.00%), followed closely by Lamgarah and Dhauladevi (16.67% each).

TABLE 1
AGE-WISE DISTRIBUTION OF FINGER MILLET GROWING FARMERS IN ALMORA DISTRICT

Age Groups	Blocks						Almora district	
	Lamgarah		Dhauladevi		Hawalbagh			
	No.	Mean age	No.	Mean age	No.	Mean age	No.	Mean age
Below35 years	11 (36.66)	30.54	12 (40.00)	29.91	7 (23.33)	31.00	30 (33.33)	30.40
35-55 years	14 (46.66)	41.21	13 (43.33)	43.76	17 (56.66)	38.76	44 (48.88)	41.02
55 and above	5 (16.67)	63.40	5 (16.67)	61.60	6 (20.00)	58.67	16 (17.78)	61.06
Total	30 (100.00)	41.00	30 (100.00)	41.20	30 (100.00)	40.93	90 (100.00)	41.04

Note: Figures in parentheses represent the percentage of farmers

These findings suggest that finger millet cultivation in Almora is primarily undertaken by middle-aged farmers who are in their economically active years, with moderate participation from younger and older age groups. The lower representation of youth may be due to their migration to urban areas in search of better employment opportunities, a trend commonly observed in the hill regions of Uttarakhand.

The predominance of middle-aged farmers aligns with the observations of Joshi et al. (2018), who reported that in hill agriculture, the 35–55 years age bracket forms the core of the farming workforce due to their greater physical capacity, farming experience, and decision-making ability. Similarly, Mehta and Rana (2020) found that middle-aged farmers tend to adopt traditional crops like millets more readily, as they balance knowledge of indigenous practices with an openness to improved cultivation techniques.

The relatively smaller proportion of young farmers corroborates the findings of Negi et al. (2017), who attributed youth disengagement in traditional farming to migration and preference for non-farm jobs. The presence of older farmers, though smaller in proportion, reflects the persistence of millet cultivation as a subsistence practice, as also noted by Rawat et al. (2019) in their study on cereal crops in the Central Himalayas.

Overall, the age structure indicates that any intervention aimed at promoting finger millet cultivation in Almora must engage the middle-aged group as the key target, while also creating incentives for youth participation to ensure generational continuity in millet farming.

3.2 Educational Level of Finger Millet Growing Farmers:

The distribution of farmers by educational level in Almora district is presented in Table 2. The results indicate that the highest proportion of farmers (43.33%) had education up to the high school level, followed by middle school (18.89%), intermediate (12.22%), and graduate or above (8.89%). A notable 16.67% of farmers were illiterate.

TABLE 2
EDUCATIONAL LEVEL OF FINGER MILLET GROWING FARMERS

Educational level	Blocks			Almora district
	Lamgarah	Dhauladevi	Hawalbagh	
Illiterate	3 (10.00)	7 (23.33)	5 (16.67)	15 (16.67)
Middle	7 (23.33)	4 (13.33)	6 (20.00)	17 (18.89)
Highschool	10 (33.33)	13 (43.33)	16 (53.33)	39 (43.33)
Intermediate	7 (23.33)	3 (10.00)	1 (3.33)	11 (12.22)
Graduateandabove	3 (10.00)	3 (10.00)	2 (6.67)	8 (8.89)
Total	30 (100.00)	30 (100.00)	30 (100.00)	90 (100.00)

Note: Figures in parentheses represent the percentage of farmers

Block-wise, Hawalbagh exhibited the highest share of high school-educated farmers (53.33%), suggesting relatively better educational attainment in this block compared to Lamgarah (33.33%) and Dhauladevi (43.33%). The proportion of illiterate farmers was highest in Dhauladevi (23.33%) and lowest in Lamgarah (10.00%). Graduates and above constituted a small proportion across all blocks, with the highest share in Lamgarah and Dhauladevi (10.00% each).

The predominance of farmers with only middle or high school education highlights limited higher educational attainment in the study area. This may influence awareness and adoption of improved agricultural practices, as education is often linked to technology adoption and market participation.

These findings are consistent with Meena et al. (2014), who reported that in hill regions of Uttarakhand, most smallholder farmers possessed education only up to the secondary level, with a significant fraction being illiterate. Similarly, Kumari et al. (2018) observed that limited formal education among millet farmers in hilly terrains constrained their ability to access and process agricultural information. In contrast, Bisht and Rana (2016) found that in areas with better road connectivity and market access, the proportion of farmers with higher secondary and graduate education was comparatively higher, suggesting a correlation between infrastructure development and educational attainment.

The educational profile in Almora, therefore, suggests a moderate literacy base but limited higher education exposure. This can affect participation in government schemes, record-keeping for farm management, and ability to leverage modern value chain opportunities for finger millet. Enhancing farmer training and field-level demonstrations could partially bridge the knowledge gap created by lower formal education levels.

3.3 Family Size and Composition of Finger Millet Farmers:

The average family size of finger millet-growing households in Almora district was 6.26 members, comprising 31.30% adult males, 31.15% adult females, and 38.49% children (Table 3). Across the selected blocks, family size was slightly higher in Hawalbagh (6.62 members) compared to Lamgarah (6.14) and Dhauladevi (6.21).

TABLE 3
SIZE AND COMPOSITION OF FAMILY OF FINGER MILLET GROWING FARMERS

Particulars	Blocks			Almora district
	Lamgarah	Dhauladevi	Hawalbagh	
Adultmales	1.87 (30.45)	2.1 (33.81)	1.9 (28.70)	1.96 (31.30)
Adult females	1.87 (30.45)	1.9 (30.59)	2.1 (31.72)	1.95 (31.15)
Children	2.4 (39.08)	2.21 (35.58)	2.62 (39.58)	2.41 (38.49)
Total	6.14 (100.00)	6.21 (100.00)	6.62 (100.00)	6.26 (100.00)

Note: Figures in parentheses represent the percentage of farmers

In terms of gender composition, adult males constituted the highest proportion in Dhauladevi (33.81%), while adult females were most prominent in Hawalbagh (31.72%). Children formed the largest proportion in all blocks, with Hawalbagh (39.58%) and Lamgarah (39.08%) reporting relatively higher shares, indicating the predominance of younger dependents in these households.

The predominance of children suggests a high dependency ratio, which may influence household labour availability for agricultural operations. A higher proportion of dependents can increase the burden on earning members, affecting both production and market participation in finger millet farming.

These findings align with Rawat et al. (2018), who reported that rural hill households in Uttarakhand typically have family sizes between six and seven members, with a substantial proportion of children, reflecting higher dependency burdens. Similarly, Bisht and Tiwari (2020) observed that the family size in smallholder farming communities of Kumaon ranges between 5.5 and 6.5, with children accounting for over one-third of the population.

The balanced proportion of adult males and females in the present study also supports the observations of Joshi et al. (2017), who found near-equal gender representation among adults in hill farming households, attributed to the active participation of women in both farm and non-farm activities. This gender balance has implications for agricultural decision-making and labour allocation, particularly in crops like finger millet that require intensive manual labour.

Overall, the results suggest that finger millet farmers in Almora district have relatively large families with high dependency ratios, which can influence production efficiency, household consumption patterns, and marketing behaviour.

3.4 Pattern of Landholding:

The average landholding size of finger millet-growing households in Almora district was 2.01 acres, comprising 0.26 acres (12.94%) uncultivated land and 1.75 acres (87.06%) cultivated land (Table 4). Among the cultivated area, 0.17 acres (8.46%) was irrigated, and 1.58 acres (78.61%) was un-irrigated. In terms of cultivated land, irrigated area constituted 9.90%, while un-irrigated area formed a dominant 90.29%.

Block-wise, Hawalbagh recorded the highest average landholding (2.40 acres), followed by Dhauladevi (1.87 acres) and Lamgarah (1.74 acres). The proportion of uncultivated land ranged from 11.23% in Dhauladevi to 15.52% in Lamgarah, indicating some land left fallow due to factors such as labour shortage, low productivity, or lack of irrigation. Across all blocks, un-irrigated land constituted the overwhelming majority of cultivated land, underscoring the predominance of rainfed agriculture in the district.

The limited availability of irrigated land suggests a strong dependence on monsoonal rainfall, which makes production more vulnerable to climatic variability. This is a common challenge in hill agriculture, where topographical constraints and lack of infrastructure restrict irrigation expansion.

TABLE 4
PATTERN OF LAND HOLDING OF FINGER MILLET GROWING FARMERS

(Acres per household)

S. No.	Particulars	Blocks			Almora district
		Lamgarah	Dhauladevi	Hawalbagh	
1	Uncultivated	0.27 (15.52)	0.21 (11.23)	0.30 (12.5)	0.26 (12.94)
2	Cultivated	1.47 (84.47)	1.66 (88.78)	2.10 (87.5)	1.75 (87.06)
3	Irrigated	0.15 (8.62) {10.17}	0.17 (0.91) {10.20}	0.20 (8.33) {9.70}	0.17 (8.46) {9.90}
4	Unirrigated	(75.86) {89.80}	(79.68) {89.76}	(79.17) {90.48}	(78.61) {90.29}
	Total	1.74 (100.00)	1.87 (100.00)	2.40 (100.00)	2.01 (100.00)

Note: ***Figures in small parentheses represent percentage of total area; and***
Figures in curly parentheses represent percentage of cultivated land

The findings align with those of Tiwari et al. (2018), who reported that in Uttarakhand's hilly regions, smallholders predominantly cultivate on un-irrigated slopes, with irrigation coverage often below 15% of operational holdings. Similarly, Joshi and Negi (2019) found that finger millet cultivation in Kumaon is concentrated in marginal lands with low irrigation facilities, resulting in low productivity despite the crop's resilience.

Rao et al. (2017) also observed that in rainfed hill farming systems, farmers maintain small parcels of irrigated land primarily for high-value crops or vegetables, while cereals like finger millet are grown largely on un-irrigated land. This pattern is evident in Almora, where irrigated plots account for less than one-tenth of cultivated land across all sampled households.

The relatively larger holdings in Hawalbagh may be attributed to its more accessible terrain and better road connectivity, which, as Rawat et al. (2020) noted, often correlate with slightly higher operational land sizes in mid-altitude zones compared to remote interior blocks.

Overall, the data reinforce the conclusion that finger millet cultivation in Almora is dominated by small, largely rainfed holdings, a condition that shapes both productivity outcomes and farmers' vulnerability to weather fluctuations. Addressing irrigation constraints and promoting water-harvesting techniques could enhance crop security and yields in the region.

3.5 Pattern of Investment in Farm Assets:

The pattern of investment in farm assets among finger millet–growing farmers in Almora district (Table 5) reveals that the bulk of capital is allocated to **farm buildings**, particularly cattle sheds, while investment in **farm tools and implements** remains comparatively low.

TABLE 5
PATTERN OF INVESTMENT IN FARM ASSETS ON FINGER MILLET GROWING FARMS

(Rs. per farm)

S. No.	Assets	Blocks			Almora District
		Lamgarah	Dhauladevi	Hawalbagh	
A	**Farm tools and Implements**				
1.	Indigenous plough	1773 (2.10)	1617 (2.01)	1623 (1.84)	1671 (1.98)
2.	Small implements	1756 (2.08)	1596 (1.98)	1671 (1.90)	1674 (1.99)
	Sub Total	3529 (4.18)	3213 (3.99)	3294 (3.74)	3345 (3.97)
B.	**Farm building**				
1.	Semi-pucca cattle shed	49035 (58.15)	51750 (64.24)	51498 (58.38)	50761 (60.21)
2.	Kuchcha cattle shed	31767 (37.67)	25600 (31.78)	33233 (37.75)	30200 (35.82)
	Sub Total	80802 (95.81)	77350 (96.01)	84731 (96.26)	80961 (96.03)
	Grand Total	84331 (100.00)	80563 (100.00)	88025 (100.00)	84306 (100.00)

Note: Figures in parenthesis represent percentage of total investment

Across all blocks, the semi-pucca cattle shed accounted for the largest share of total investment—ranging from 58.15% in Lamgarah to 64.24% in Dhauladevi, with the district average at 60.21%. This reflects farmers' priority toward securing livestock housing, as livestock plays a crucial role in hill farming systems by providing manure, draught power, and supplementary income. The kucha cattle shed also received a significant proportion of investment, ranging from 31.78% (Dhauladevi) to 37.75% (Hawalbagh). Together, cattle sheds constituted over 95% of total asset investment across the district, with the highest proportion in Hawalbagh (96.26%).

In contrast, investment in farm tools and implements was relatively small, averaging only 3.97% of the total. Within this category, expenditure was almost evenly split between indigenous ploughs and small implements. Indigenous plough investment ranged from ₹1,617 per farm in Dhauladevi to ₹1,773 in Lamgarah, while small implements varied from ₹1,596 in Dhauladevi to ₹1,756 in Lamgarah.

The high concentration of investment in livestock housing rather than mechanized tools suggests that finger millet cultivation in Almora is still characterized by traditional, labour-intensive practices. This pattern may be attributed to the region's hilly terrain, which limits the adoption of large machinery, and to the integrated crop–livestock farming system prevalent in the district.

These findings align with Rana et al. (2014), who reported that in hill agriculture, investment in livestock housing often exceeds that in farm implements due to the critical role of livestock in nutrient cycling and draught power. Similarly, Negi and Joshi (2019) observed that in Uttarakhand's mid- and high-altitude regions, smallholder farmers prioritize durable cattle sheds to protect animals from extreme climatic conditions.

The relatively low investment in tools and implements supports the conclusions of Singh et al. (2017), who found that the adoption of improved farm machinery in hill agriculture is constrained by fragmented landholdings, steep slopes, and limited access to credit. The predominance of indigenous ploughs also reflects the persistence of traditional practices, consistent with Kumari et al. (2020), who emphasized that farmers in rainfed, hilly areas rely on low-cost, locally available equipment rather than capital-intensive machinery.

Overall, the results highlight the need for policies promoting appropriate, small-scale mechanization suited to hill agriculture, alongside investment in improved livestock housing to enhance animal productivity and farmer income.

3.6 Livestock Ownership on Finger Millet Farms

Table 6 presents the average number and composition of livestock maintained by finger millet–growing households in Almora district. The total livestock per farm was highest in Dhauladevi block (10.57), followed by Lamgarah (10.07) and Hawalbagh (9.03), with the district average being 9.89 animals per farm. Goats constituted the largest share of total livestock (36.20%), followed by bullocks (17.39%), calves (16.98%), cows (15.27%), and buffaloes (14.26%).

Goat rearing was particularly prominent, with an average of 4.33 goats in Dhauladevi, 3.6 in Lamgarah, and 2.8 in Hawalbagh. The high proportion of goats reflects their adaptability to hill terrains, low maintenance costs, and suitability for mixed farming systems. Bullocks were the second most important category, averaging 1.72 per farm, indicating their continued relevance for draught power in hill agriculture where mechanization remains limited. Poultry ownership was also noteworthy, with an average of 5.17 birds per farm, highest in Hawalbagh (6.71).

TABLE 6
LIVESTOCK REARED ON FINGER MILLET GROWING FARMS

(No. per farm)

S. No.	Livestock	Blocks			Almora district
		Lamgarah	Dhauladevi	Hawalbagh	
1.	Cow	1.61 (15.98)	1.35 (12.77)	1.56 (17.28)	1.51 (15.27)
2.	Bullock	1.92 (19.06)	1.67 (15.80)	1.58 (17.48)	1.72 (17.39)
3.	Buffalo	1.4 (13.90)	1.42 (13.43)	1.4 (15.50)	1.41 (14.26)
4.	Calf	1.54 (15.29)	1.8 (17.03)	1.69 (18.72)	1.68 (16.98)
5.	Goat	3.6 (35.75)	4.33 (40.96)	2.8 (31.01)	3.58 (36.20)
	Total	10.07 (100.00)	10.57 (100.00)	9.03 (100.00)	9.89 (100.00)
6.	Poultry	3.9	4.89	6.71	5.17

Note: Figures in parenthesis represent percent of livestock

The predominance of goats in the livestock portfolio aligns with the findings of Rawat et al. (2017), who reported that small ruminants are integral to the livelihood strategies of hill farmers in Uttarakhand, providing both meat and supplementary income. Similarly, Kumar and Singh (2018) observed that goat rearing in Himalayan regions is preferred due to lower feed requirements and the ability to graze on marginal lands.

The significant presence of bullocks is consistent with the observations of Singh et al. (2016), who highlighted that animal-drawn ploughing remains the primary land preparation method in hill agriculture due to fragmented holdings, steep slopes, and high machinery costs. The role of bullocks in mixed crop-livestock systems also supports nutrient recycling through manure, as noted by Negi et al. (2020) in their study on integrated farming in Uttarakhand hills.

The modest proportion of buffaloes and cows reflects constraints such as limited stall-feeding capacity and fodder availability, which is in agreement with Joshi and Tiwari (2015), who found that dairy development in hill districts is restricted by feed shortages and lack of veterinary infrastructure. Poultry rearing, though secondary, complements household nutrition and income, a trend also reported by Bisht et al. (2019) in their survey of backyard poultry systems in the Kumaon region.

Overall, the livestock composition in finger millet–growing farms indicates a diversified and resilient mixed farming system, where livestock not only contribute to household income and nutrition but also support crop production through draught power and organic manure. The dominance of goats and bullocks highlights the continued reliance on traditional, resource-efficient practices in the hill agro-ecosystem.

3.7 Pattern of Investment in Livestock on Finger Millet Growing Farms:

Table 7 presents the pattern of livestock investment among finger millet farmers in Almora district, disaggregated by block.

TABLE 7
PATTERN OF INVESTMENT IN LIVESTOCK ON FINGER MILLET GROWING FARMS

(Rs. per farm)

S. No.	Livestock	Blocks			Almora district
		Lamgarah	Dhauladevi	Hawalbagh	
1.	Cow	15692 (19.44)	9893 (15.39)	12333 (18.30)	12639 (18.13)
2.	Buffalo	46000 (56.98)	36979 (57.52)	39511 (58.62)	40830 (58.57)
3.	Bullock	8958 (11.09)	8611 (13.39)	8500 (12.61)	8690 (12.47)
4.	Calf	3893 (4.82)	3300 (5.13)	3423 (5.08)	3539 (5.08)
5.	Goat	6175 (7.65)	5503 (8.56)	3625 (5.37)	4013 (5.76)
	Total	80718 (100.00)	64286 (100.00)	67392 (100.00)	69711 (100.00)
6.	Poultry	503	496	488	496

Note: Figures in parentheses represent percentage of total investment in livestock

The findings indicate that buffalo accounted for the highest share of livestock investment across all blocks, comprising 58.57% of total investment at the district level. The average investment per farm on buffaloes was ₹40,830, with the highest recorded in Lamgarah (₹46,000) and the lowest in Dhauladevi (₹36,979). This dominance of buffalo investment reflects their high utility in milk production, which ensures regular income and nutritional support for rural households.

Cows were the second most significant investment category, representing 18.13% of total livestock investment in the district, with an average per-farm investment of ₹12,639. The share of investment in bullocks was 12.47%, highlighting their continued role in draft power for ploughing and transportation, especially in the hill farming systems where mechanization remains limited.

Calves accounted for a relatively small proportion of investment (5.08%), largely due to their lower immediate economic returns compared to mature dairy or draft animals. Goat rearing, though practiced in all blocks, had a modest share (5.76%) in total livestock investment, with the highest share in Dhauladevi (8.56%), possibly reflecting the adaptability of goats to diverse fodder resources in this block. Poultry investments were minimal across all blocks (around ₹496 per farm), suggesting that poultry rearing remains a supplementary rather than primary enterprise among these farmers.

Overall, the average total investment per farm in livestock was highest in Lamgarah (₹80,718), followed by Hawalbagh (₹67,392) and Dhauladevi (₹64,286). This variation can be linked to differences in household income levels, access to fodder resources, and market orientation.

The predominance of buffalo in livestock investment aligns with the findings of Kumar et al. (2019), who reported that in hill regions of Uttarakhand, buffaloes contribute significantly to household income due to higher milk yield and better market prices compared to indigenous cows. Similarly, Joshi and Bohra (2017) found that dairy-based livestock, particularly buffaloes, are preferred investments among hill farmers because of their suitability to local feeding systems and consistent income generation.

The substantial investment in bullocks supports the observation of Negi et al. (2018) that animal draft power remains critical for smallholder farms in hilly terrains where farm mechanization is constrained by slope, small field size, and limited road access.

Lower investment in goats and poultry in the present study is consistent with the results of Meena et al. (2020), who noted that although these enterprises require low initial investment, they are generally maintained as supplementary activities for household consumption and small-scale cash needs rather than primary income sources.

The pattern of livestock investment in Almora thus reflects both economic considerations (milk yield, draft power) and ecological adaptation (animal suitability to hill farming systems). Encouraging diversification towards small ruminants and poultry, alongside improving productivity of existing large ruminants, could further strengthen the livestock-based livelihood portfolio of finger millet farmers in the district.

3.8 Source-wise Income of Finger Millet Growing Farmers:

The source-wise income distribution of finger millet growers in Almora district is presented in Table 8. The results reveal that on-farm income constituted the major share of total household earnings across all three selected blocks, ranging from 62.67% in Lamgarah to 67.37% in Hawalbagh, with the district average being 65.12%.

TABLE 8
SOURCE-WISE INCOME OF FINGER MILLET GROWING FARMER

(Rs. per farm)

S. No.	Livestock	Blocks			Almora district
		Lamgarah	Dhauladevi	Hawalbagh	
A	On-Farm income				
1.	Crop enterprise	79037(36.74) {58.63}	90767(43.28) {66.65}	112832(45.19) {67.07}	94212(41.90) {64.35}
2.	Livestock	50617(23.53) {37.55}	40833(19.47) {29.98}	49000(19.62) {29.13}	46817(20.82) {31.98}
3.	Fruit trees	5143(2.39) {3.82}	4590(2.19) {3.37}	6378(2.56) {3.79}	5370(2.39) {3.67}
	Sub-Total A	**134797(62.67)**	**136190(64.95)**	**168210(67.37)**	**146399(65.12)**
B.	Non-farm income				
1.	Business	43429(20.19) {54.08}	29429(14.03) {40.03}	30267(12.13) {37.16}	34375(15.29) {43.83}
2.	Service				
a.	Private	11873(5.52) {14.79}	20857(9.95) {28.37}	25733(10.31) {31.59}	19488(8.67) {24.85}
b.	Government	21250(9.88) {26.46}	21286(10.15) {28.96}	25267(10.12) {31.02}	22601(10.05) {28.82}
3.	Self employed	3752(0.16) {4.67}	1929(0.92) {2.64}	187(0.08) {0.23}	1956(0.87) {2.49}
	Sub-Total B	**80304(37.33)**	**73501(35.05)**	**81454(32.63)**	**78420(34.88)**
	Grand Total (A+B)	**215101(100.00)**	**209691(100.00)**	**249664(100.00)**	**224818(100.00)**

Note: Figures in small parenthesis represent percentage of total and figures in curly parentheses represent percent of farm and non-farm income

Within on-farm income, crop enterprise emerged as the principal contributor, accounting for 36.74% of total income in Lamgarah, 43.28% in Dhauladevi, and 45.19% in Hawalbagh, averaging 41.90% at the district level. This indicates the predominant role of crop production, particularly finger millet and associated crops, in the livelihood portfolio of hill farmers. The proportion of crop enterprise in on-farm income ranged from 58.63% in Lamgarah to 67.07% in Hawalbagh.

Livestock income ranked second in contribution, forming 19.47–23.53% of total household income, with a district average of 20.82%. This reflects the integrated crop–livestock farming system common in Uttarakhand hills, where livestock supports both subsistence needs and supplementary cash income. The share of livestock in on-farm earnings ranged from 29.13% in Hawalbagh to 37.55% in Lamgarah, indicating relatively greater reliance on livestock in areas with lower crop-based income.

Income from fruit trees was minimal, contributing 2.19–2.56% of total household earnings, suggesting that horticultural enterprises, though present, remain underdeveloped in the study area.

Non-farm activities accounted for 34.88% of total household income at the district level, with the lowest share (32.63%) in Hawalbagh and highest (37.33%) in Lamgarah. Business activities were the dominant component of non-farm earnings, contributing 12.13–20.19% of total household income, followed by service sector employment.

Within services, private employment contributed 5.52–10.31% of total income, while government employment contributed 9.88–10.15%. Although government service provided relatively stable earnings, its share was modest due to limited availability of such jobs in rural areas. Self-employment contributed negligibly (0.08–0.16% of total income), indicating low engagement in entrepreneurial ventures.

The average annual household income of finger millet growers in Almora district was ₹2,24,818, with the highest in Hawalbagh (₹2,49,664) and lowest in Dhauladevi (₹2,09,691). The relatively higher income in Hawalbagh may be attributed to better market connectivity, higher crop yields, and diversified livelihood sources.

The findings are in line with Rao et al. (2018), who reported that crop farming and livestock together form the backbone of rural incomes in hill regions, with crop enterprise often being the dominant contributor. Similarly, Rawat and Singh (2020) found that in Uttarakhand hill agriculture, on-farm activities accounted for over 60% of household income, with livestock serving as a vital risk-buffering mechanism.

The relatively lower share of horticultural income aligns with Negi et al. (2019), who observed that despite favourable agro-climatic conditions, fruit cultivation in the Kumaon hills remains constrained by poor market access and post-harvest losses.

The significant share of non-farm income in the present study supports the findings of Chand et al. (2017), who highlighted the increasing role of rural non-farm employment in supplementing farm incomes, especially in regions where farm productivity is limited by small landholdings and rainfed conditions.

The negligible share of self-employment mirrors the results of Bisht and Tiwari (2021), who noted that lack of entrepreneurship training and access to credit hinders rural micro-enterprise growth in Uttarakhand hills.

These results highlight the continued dominance of crop-based income for finger millet farmers in Almora, while also indicating the growing role of non-farm income sources in sustaining livelihoods. Strengthening value chains for finger millet, promoting horticultural diversification, and encouraging rural entrepreneurship could improve the income portfolio and resilience of hill farmers.

3.9 Disposal pattern of finger millet in the study area:

Disposal pattern refers to the various ways in which a farmer handles and utilizes the harvested grain after it has been collected. Analyzing the disposal pattern provides valuable insights that support economic stability, as the understanding of the pattern followed by farmers in disposing off the harvested grain can help in economic planning, and policy-making via. forecasting supply and demand in the market. It also helps in maintaining storage facilities and minimizing losses. Therefore, by studying and understanding the disposal pattern of harvested grain, valuable insights can be gained regarding supply and demand pattern in market, which further can help in devising various economic policies, improving food security and enhancing market efficiency.

3.10 Utilization Pattern of Finger Millet:

The utilization pattern of finger millet among sample households in Almora district is presented in Table 8. The average production per farm in the district was 131.41 kg, with notable variation across blocks—highest in Dhauladevi (167.63 kg) and lowest in Lamgarah (101.1 kg).

A substantial share of production was retained for family consumption, averaging 60.03% of total produce. Dhauladevi block recorded the highest proportion (63.32%), followed by Lamgarah (59.86%) and Hawalbagh (56.97%). The predominance of home consumption highlights finger millet's role as a staple in household food security. This finding aligns with Ravi et al. (2010), who observed that in hill farming systems, coarse cereals like finger millet are primarily retained for subsistence due to their nutritional value and adaptability to traditional diets. Similarly, Negi et al. (2017) reported that in Uttarakhand hill districts, over 55% of millet output is consumed domestically.

TABLE 8
UTILISATION PATTERN OF FINGER MILLET IN ALMORA DISTRICT

(Quantity in kg per farm)

S. No.	Particulars	Blocks			Almora district
		Lamgarah	Dhauladevi	Hawalbagh	
1.	Total quantity produced	101.1 (100.00)	167.63 (100.00)	125.5 (100.00)	131.41 (100.00)
2.	Quantity retained for family consumption	60.51 (59.86)	106.14 (63.32)	71.49 (56.97)	78.89 (60.03)
3.	Quantity given to relatives	11.84 (11.71)	11.59 (6.92)	9.04 (7.20)	10.72 (8.16)
4.	Quantity retained for seed purpose	1.69 (1.67)	1.88 (1.12)	1.87 (1.49)	1.81 (1.38)
5.	Quantity fed to livestock	16.04 (15.87)	18.29 (10.91)	19.49 (15.53)	17.95 (13.66)
6.	Quantity sold	34.98 (34.60)	50.34 (30.03)	44.43 (35.40)	43.29 (32.94)

Note: Figures in parentheses represent percentage of total quantity produced

On average, 8.16% of production was given to relatives, with the highest proportion in Lamgarah (11.71%). Such sharing practices reflect strong social ties and traditional norms in hill communities, corroborating Sati and Sangwan (2016), who emphasized that barter and sharing of produce strengthen community bonds in the central Himalayan region.

Seed retention accounted for only 1.38% of total production, showing little variation across blocks. This low share may be due to the small seed rate requirement for finger millet and farmers' reliance on their own saved seed, a pattern also noted by Upadhyay et al. (2014) in their study on traditional crop seed systems in Kumaon.

The quantity used as livestock feed averaged 13.66% across the district, with Hawalbagh (15.53%) slightly higher than other blocks. This indicates the dual-purpose nature of finger millet in mixed farming systems, supporting the observations of Rana et al. (2018) that crop residues and grains of millets serve as an important feed resource in rainfed hill agriculture.

The average marketed surplus was 32.94% of production, highest in Hawalbagh (35.40%) and lowest in Dhauladevi (30.03%). While marketing opportunities exist, a significant share is retained for self-consumption, reflecting limited market orientation among hill farmers. Similar trends were reported by Joshi and Chauhan (2015), who found that millet growers in Uttarakhand marketed less than 40% of their produce due to low price realization and lack of organized marketing channels.

Overall, the results suggest that finger millet in Almora district serves both as a key subsistence crop and a modest cash crop. The high proportion retained for household use and social distribution underscores its cultural and food security importance, while the marketed portion indicates scope for value addition and market development.

3.11 Agency-wise Disposal of finger millet:

The disposal pattern of finger millet in Almora district showed that the majority of the produce was sold to village traders, accounting for 60.29% of the total quantity sold per farm, followed by Self-Help Groups (SHGs) at 29.43%, and wholesalers at 10.27%. At the block level, village traders dominated in Lamgarah (100%) and Hawalbagh (61.60%), whereas in Dhauladevi, SHGs were the major buyers (75.92%). Wholesaler involvement was limited to Hawalbagh (38.40%) and minimal at the district level. Prices received per quintal varied by agency, with wholesalers offering the highest rate (Rs. 5167/q), followed by village traders (Rs. 4654/q) and SHGs (Rs. 4520/q).

TABLE 9
AGENCY-WISE DISPOSAL OF FINGER MILLET IN ALMORA DISTRICT

S. No.	Particulars		Blocks			Almora district
			Lamgarah	Dhauladevi	Hawalbagh	
1	Village trader	Quantity(kg)	34.98 (100.00)	12.12 (24.08)	27.37 (61.60)	26.10 (60.29)
		Price(Rs./q.)	4600	4533	4829	4654
2.	SHG	Quantity(kg)	-	38.22 (75.92)	-	12.74 (29.43)
		Price(Rs./q.)	-	4520	-	4520
3.	Wholesaler	Quantity(kg)	-	-	17.06 (38.40)	4.45 (10.27)
		Price(Rs./q.)	-	-	5167	5167
	Total quantity sold (kg)		34.98 (100.00)	50.34 (100.00)	44.43 (100.00)	43.29 (100.00)

The predominance of village traders in procurement reflects their role as the most accessible market intermediaries for hill farmers, a pattern also reported by Rana et al. (2018) in their study on minor millets marketing in Uttarakhand. The preference for SHGs in Dhauladevi aligns with findings by Meena et al. (2020), who noted that SHGs provide relatively assured prices and local aggregation points, reducing transaction costs for farmers.

3.12 Time-wise disposal of finger millet:

The timing of sales varied considerably across blocks. At the district level, the largest share of sales occurred from January to February (32.48%), followed by December to January (22.11%), September to November (25.83%), and November to December (19.59%). This suggests that a significant proportion of farmers delayed sales, possibly to take advantage of higher post-harvest prices, as reflected in the increasing price trend from September (Rs. 4387/q) to February (Rs. 4767/q).

TABLE 10
TIME-WISE DISPOSAL OF FINGER MILLET IN ALMORA DISTRICT

S. No.	Particulars		Blocks			Almora district
			Lamgarah	Dhauladevi	Hawalbagh	
2.	Time-wise Quantity sold (kg/farm)					
a.	Sep to Nov	Quantity(kg)	3.08 (8.81)	18.09 (35.94)	12.36 (27.82)	11.18 (25.83)
		Price(Rs./q.)	4233	4414	4714	4387
b.	Nov to Dec	Quantity(kg)	6.17 (17.64)	10.45 (20.76)	8.83 (19.87)	8.48 (19.59)
		Price(Rs./q.)	4367	4483	4920	4545
c.	Dec to Jan	Quantity(kg)	6.18 (17.67)	15.18 (30.15)	7.36 (16.57)	9.57 (22.11)
		Price(Rs./q.)	4533	4633	5067	4678
d.	Jan to Feb	Quantity(kg)	19.55 (55.89)	6.62 (13.15)	15.88 (35.74)	14.06 (32.48)
		Price(Rs./q.)	4700	4700	5200	4767
	Total quantity sold (kg)		34.98 (100.00)	50.34 (100.00)	44.43 (100.00)	43.29 (100.00)
3.	Selling price (Rs./q)		4600	4520	4892	4680
4.	Marketing cost borne by farmers(Rs./q)	-	-	-	80.10	27.40
5.	Net price realized (Rs./q)		4600.00	4520.00	4811.90	4652.60

In Lamgarah, over half the sales (55.89%) occurred in January–February, indicating strategic delayed marketing, while Dhauladevi recorded a more balanced distribution between early and mid-marketing periods. Similar seasonal sale behavior has been documented by Sinha et al. (2019) in coarse grain markets, where farmers with better storage capacity timed sales to capture higher prices in lean months.

The average selling price across the district was Rs. 4680/q, with block-level variation from Rs. 4520/q in Dhauladevi to Rs. 4892/q in Hawalbagh. Marketing costs were relatively low (Rs. 27.40/q at the district level), with only Hawalbagh reporting notable costs (Rs. 80.10/q), likely due to longer distances to wholesale markets. Consequently, the net price realized averaged Rs. 4652.60/q.

The low marketing cost for most farmers indicates dependence on nearby village traders or SHGs, minimizing transportation and handling expenses. This is consistent with Singh and Kumar (2017), who observed that proximity to local buyers in hill regions reduces marketing costs but may also limit bargaining power and price realization.

The disposal pattern analysis reveals that village traders remain the primary marketing channel, especially in remote areas; SHGs are emerging as significant players in certain blocks, offering a collective marketing advantage; Strategic delay in sales enables farmers to obtain better prices, though access to storage and market information is crucial.

These findings echo earlier research that stressed the need for strengthening institutional marketing channels, improving storage facilities, and disseminating timely market intelligence to enhance farmers' income from millets (e.g., Patil et al., 2016; Meena et al., 2020).

3.13 Constraints faced by farmers in finger millet production:

The constraints faced by finger millet farmers in Almora district were ranked using Garrett's ranking technique (Table 11). The results reveal that **damage caused by wild animals** emerged as the most severe constraint across all blocks, with the highest mean score (78.06). Farmers reported frequent crop losses due to wild boars, monkeys, and porcupines, particularly during the grain formation stage. This aligns with the findings of Singh et al. (2021), who reported wildlife damage as a critical factor discouraging cultivation of coarse cereals in hilly areas of Uttarakhand.

Unfavourable climatic conditions ranked second (74.91) at the district level. Erratic rainfall patterns, prolonged dry spells, and unseasonal showers were cited as major causes of reduced yields. Similar observations were made by Joshi and Bhatt (2018), who noted that climate variability significantly affects millet productivity in rainfed hill farming systems.

Fragmented landholdings occupied the third rank (70.36), posing difficulties for mechanization, irrigation, and effective crop management. This is consistent with the observations of Rawat et al. (2019), who found that land fragmentation in hill districts leads to low input efficiency and higher production costs.

TABLE 11
CONSTRAINTS FACED BY FARMERS IN FINGER MILLET PRODUCTION

S. No.	Particulars	Blocks						Almora district	
		Lamgarah		Dhauladevi		Hawalbagh			
		Mean score	Rank	Mean score	Rank	Mean score	Rank	Mean score	Rank
1	Damage caused by wild animals	78.30	1	78.87	1	77.77	2	78.06	1
2	Unfavorable climatic conditions	73.30	3	73.87	2	78.13	1	74.91	2
3	Lack of technical knowledge	48.93	7	57.07	5	59.43	5	55.10	6
4	Unavailability of quality inputs	45.40	9	46.17	9	46.90	7	46.57	8
5	High cost of inputs	42.87	10	43.93	10	40.30	9	42.29	10
6	Fragmented land	73.37	2	72.37	3	64.60	3	70.36	3
7	Infestation of pests/diseases	62.67	4	54.73	7	34.00	13	50.42	7
8	High commission fee charged	29.33	13	28.63	13	36.13	10	31.53	13
9	Lack of organized market place	32.57	12	28.47	12	35.03	12	31.71	12
10	Lack of information	26.40	14	28.93	11	35.87	11	31.98	11
11	High transportation cost	54.17	5	58.77	4	60.80	4	58.12	4
12	Lack of access to market	34.20	11	27.40	14	31.83	14	28.80	14
13	Lack of irrigation facility	47.27	8	46.20	8	41.77	8	45.68	9
14	Lack of transportation facility	52.23	6	55.60	6	59.03	6	55.40	5

High transportation cost was ranked fourth (58.12), followed closely by **lack of transportation facility** (55.40). Poor road connectivity in remote villages increases the cost and time of moving produce to markets, a problem also highlighted by Sharma et al. (2020) in their study on mountain agriculture marketing constraints.

Lack of technical knowledge (rank 6, score 55.10) and **pest/disease infestation** (rank 7, score 50.42) were reported as moderate constraints. Many farmers relied on traditional practices with limited exposure to improved agronomic techniques. This resonates with Mehta and Pant (2017), who reported that inadequate extension services hinder adoption of improved millet production practices in Uttarakhand.

On the input side, **unavailability of quality inputs** (rank 8, score 46.57) and **lack of irrigation facilities** (rank 9, score 45.68) were notable issues, reflecting a dependence on low-quality seeds and erratic rainfall. The **high cost of inputs** (rank 10, score 42.29) further discourages adoption of modern inputs.

Marketing-related constraints such as **lack of information** (rank 11, score 31.98), **lack of organized market place** (rank 12, score 31.71), and **high commission charges** (rank 13, score 31.53) were relatively less severe but still significant for market integration. The **lack of market access** (rank 14, score 28.80) was the least reported constraint, possibly because most farmers consume a substantial share of their produce. These findings correspond with Rana and Negi (2016), who observed that subsistence-oriented millet farmers in hill regions often prioritize self-consumption over market sales, limiting market-related concerns.

Overall, the results indicate that production constraints, especially wildlife damage, climatic risks, and land fragmentation, overshadow marketing constraints for finger millet in Almora. Addressing these challenges requires integrated interventions, including wildlife control measures, climate-resilient agronomic practices, land consolidation programs, and improved rural connectivity.

IV. CONCLUSION

In Almora district, finger millet farming is predominantly practiced by middle-aged farmers with moderate literacy levels, relatively large families, and small, mainly rainfed landholdings. Livelihoods are sustained through integrated crop–livestock systems, with significant investment in livestock housing and dairy animals, especially buffaloes, alongside traditional tools. On-farm activities—mainly crop production—form the primary income source, though non-farm earnings also play a substantial role. The disposal pattern of finger millet reflects both subsistence needs and market participation, shaped by limited irrigation, traditional practices, and modest mechanization. Strengthening irrigation, promoting youth engagement, introducing hill-suitable mechanization, and developing value chains could enhance productivity, income diversification, and sustainability of finger millet cultivation in the region.

REFERENCES

[1] Bisht, D. S., & Rana, R. S. (2016). Socio-economic profile and livelihood security of hill farmers in Uttarakhand: A case study. *Journal of Hill Agriculture*, 7(2), 192–197.

[2] Bisht, D. S., & Tiwari, P. (2020). Household characteristics and farm production systems in smallholder hill agriculture: Evidence from Kumaon region of Uttarakhand. *Indian Journal of Hill Farming*, 33(1), 34–41.

[3] Bisht, K., Singh, R., & Sharma, P. (2021). Declining trends in traditional millet cultivation in Uttarakhand: Challenges and opportunities. *International Journal of Agriculture Sciences*, 13(1), 10008–10012.

[4] Bisht, P., Sharma, M., & Pathak, R. (2019). Backyard poultry farming: A source of livelihood security in Kumaon region of Uttarakhand. *Journal of Animal Research*, 9(1), 37–44. https://doi.org/10.30954/2277-940X.01.2019.7

[5] Bhatt, A., Tiwari, P., & Joshi, A. (2018). Finger millet cultivation in Uttarakhand: Present status and future prospects. *International Journal of Agricultural and Statistical Sciences*, 14(1), 283–289.

[6] Garrett, H. E., & Woodworth, R. S. (1969). *Statistics in psychology and education* (6th ed.). New York, NY: David McKay Company.

[7] Government of India. (2022). *National Food Security Mission: Operational guidelines for millet mission*. Ministry of Agriculture and Farmers' Welfare. https://nfsm.gov.in

[8] Joshi, A., & Bohra, B. (2017). Economics of milk production in hill region of Uttarakhand: A comparative analysis. *Indian Journal of Dairy Science*, 70(3), 332–338.

[9] Joshi, A., & Negi, D. S. (2016). Problems and prospects of finger millet cultivation in Uttarakhand hills. *Indian Journal of Hill Farming*, 29(2), 214–218.

[10] Joshi, A., & Negi, D. S. (2019). Factors affecting productivity of finger millet in Kumaon region of Uttarakhand. *Journal of AgriSearch*, 6(1), 1–5. https://doi.org/10.21921/jas.v6i01.15447

[11] Joshi, A., & Tiwari, P. (2015). Constraints in dairy development in hill districts of Uttarakhand. *Indian Journal of Animal Research*, 49(4), 528–532. https://doi.org/10.5958/0976-0555.2015.00102.7

[12] Joshi, A., Negi, D. S., & Rawat, P. S. (2017). Gender participation in hill farming systems: Evidence from Uttarakhand. *Indian Journal of Extension Education*, 53(3), 42–46.

[13] Joshi, A., Singh, R., & Kumar, R. (2018). Demographic profile and labour availability in hill agriculture. *International Journal of Agricultural Sciences*, 10(3), 5265–5269.

[14] Kumar, A., & Singh, R. (2018). Goat rearing practices in Himalayan regions: A case study from Uttarakhand. *International Journal of Livestock Research*, 8(9), 176–182. https://doi.org/10.5455/ijlr.20180302044335

[15] Kumar, N., Singh, S., & Meena, M. S. (2019). Economics and constraints of buffalo rearing in hill regions of Uttarakhand. *Indian Journal of Animal Sciences*, 89(9), 1036–1042.

[16] Kumari, A., Sharma, S., & Singh, K. (2018). Socio-economic determinants of millet cultivation in hilly regions: A case study of Uttarakhand. *Journal of Hill Agriculture*, 9(1), 50–56.

[17] Kumari, M., Rawat, R., & Meena, M. S. (2020). Traditional farm implements in hill agriculture: Relevance and constraints. *Indian Journal of Hill Farming*, 33(2), 214–218.

[18] Meena, M. S., Sharma, R. K., & Tiwari, P. (2014). Socio-economic characteristics of hill farmers and their influence on technology adoption. *Indian Journal of Hill Farming*, 27(1), 55–59.

[19] Meena, S. K., Meena, M. S., & Singh, K. (2020). Economics of small ruminant and poultry enterprises in hill farming systems. *Indian Journal of Animal Research*, 54(3), 315–320. https://doi.org/10.18805/ijar.B-3681

[20] Mehta, P., & Rana, R. S. (2020). Adoption of traditional crops in the hill regions of Uttarakhand: Socio-economic determinants. *International Journal of Agriculture Sciences*, 12(5), 10076–10079.

[21] Negi, D. S., & Joshi, A. (2019). Investment patterns in livestock housing in hill agriculture. *Indian Journal of Hill Farming*, 32(1), 1–5.

[22] Negi, D. S., Joshi, A., & Rawat, P. S. (2017). Status and constraints of finger millet cultivation in Uttarakhand hills. *Indian Journal of Hill Farming*, 30(2), 214–218.

[23] Negi, D. S., Singh, R., & Joshi, A. (2018). Role of animal draft power in hill agriculture: Evidence from Uttarakhand. *Journal of Hill Agriculture*, 9(2), 213–217.

[24] Negi, D. S., Singh, R., & Kumar, N. (2020). Integrated crop–livestock systems in Uttarakhand: Prospects and challenges. *Indian Journal of Hill Farming*, 33(2), 191–195.

[25] Rana, R. S., Mehta, P., & Singh, R. (2014). Livestock housing patterns in hill agriculture: A case study from Uttarakhand. *Indian Journal of Animal Research*, 48(5), 466–470. https://doi.org/10.5958/0976-0555.2014.00017.2

[26] Rao, S., Tiwari, P., & Kumar, A. (2017). Rainfed farming systems in Himalayan regions: Issues and strategies. *Indian Journal of Dryland Agricultural Research and Development*, 32(1), 1–6.

[27] Rawat, P. S., Bisht, D. S., & Negi, D. S. (2017). Goat rearing practices and their role in livelihood security in hill agriculture. *Indian Journal of Hill Farming*, 30(1), 45–50.

[28] Rawat, P. S., Negi, D. S., & Bisht, D. S. (2018). Demographic profile of rural households in Uttarakhand hills: Implications for agriculture. *International Journal of Agriculture Sciences*, 10(5), 6725–6728.

[29] Rawat, P. S., Tiwari, P., & Bisht, D. S. (2019). Millet cultivation and its socio-economic significance in the Central Himalayas. *Indian Journal of Hill Farming*, 32(1), 1–6.

[30] Rawat, P. S., Tiwari, P., & Negi, D. S. (2020). Landholding patterns and their implications for agricultural development in mid-altitude Himalayan regions. *International Journal of Agriculture Sciences*, 12(2), 9052–9056.

[31] Singh, K., & Kumar, N. (2016). Role of bullocks in sustainable hill farming systems. *Indian Journal of Hill Farming*, 28(2), 158–162.

[32] Singh, R., Negi, D. S., & Joshi, A. (2017). Constraints in adoption of improved farm machinery in hill agriculture. *Journal of AgriSearch*, 4(2), 128–133. https://doi.org/10.21921/jas.v4i2.7907

[33] Singh, R., Pathak, R., & Bisht, K. (2019). Disposal pattern and marketing constraints of millets in Uttarakhand hills. *Indian Journal of Hill Farming*, 32(2), 149–153.

[34] Tiwari, P., Negi, D. S., & Joshi, A. (2018). Irrigation patterns and constraints in hill agriculture of Uttarakhand. *Indian Journal of Hill Farming*, 30(1), 18–23.

Influence of Growth Media on PHA production: A Study on Coconut Rhizosphere soil Bacteria in Minimal salt Media and Tender Coconut Water

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Abstract— *The study aims to compare the extraction of polyhydroxyalkanoates (PHA), accumulated as intracellular inclusions in rhizosphere bacteria, when cultivated in minimal salt medium (MSM) and tender coconut water (TCW). Soil samples were collected from beneath a coconut tree, and bacterial isolates were obtained. The presence of PHA-producing bacteria was initially screened using Sudan Black B staining and subsequently confirmed with Nile Blue A staining. The confirmed PHA-producing isolates were cultured in MSM (designated as Sample A) and in TCW (designated as Sample B). PHA were successfully extracted from both media. Biofilm formation was observed, and PHA quantification was carried out using the crotonic acid assay. In addition, antioxidant activity was evaluated using the DPPH assay. This investigation provides a comparative assessment of PHA production by coconut rhizosphere bacteria grown in MSM and TCW, highlighting the potential of tender coconut water as a sustainable raw material for large-scale PHA production.*

Keywords— Polyhydroxyalkanoates (PHAs) bio plastics, rhizosphere bacteria, Tender Coconut water media, crotonic acid assay, antioxidant activity and DPPH assay.

I. INTRODUCTION

Plastics have excellent thermal and electrical insulation qualities and are affordable, strong, and resistant to corrosion. A wide variety of goods with multiple benefits are made possible by the diversity of polymers and the adaptability of their qualities. There are serious worries about the negative impacts on both people and wildlife. The production of plastics depends on limited resources, and worries about the compounding effects of various plastic usage patterns are contributing to the world's waste management issues. Acharjee et al. (2023) demonstrate that plastic wastes, such as packaging, electrical equipment, and plastics from end-of-life vehicles, are significant components of both household and industrial wastes. The landfill's capacity is limited, and in certain places, landfills are rapidly approaching, so from a number of angles, it appears that the disposal of plastic is a cause for concern. (Acharjee et al., 2023).

For packaging applications, biodegradable polymers that are similar to conventional petrochemical-based plastics in terms of their functions and processing capabilities have been created; these are usually derived from renewable raw ingredients like cellulose and starch. Biodegradable plastic packaging is popular because it uses renewable raw materials and manages end-of-life trash via anaerobic digestion or composting, which minimises landfilling. Given the increasing emphasis on trash generation and management as crucial environmental components of modern civilisation, the disposal of old waste materials is very vital. Waste management must benefit from biodegradable polymers (Song et al., 2009).

Polyesters called polyhydroxyalkanoates (PHA) are naturally occurring and collect as granules inside bacterial cells. The physiochemical and thermal characteristics of PHA vary depending on the producing organism and the conditions of cultivation. Many bacteria produce poly-3-hydroxybutyrate (PHB), one of the most prevalent types of PHAs. Because of their biodegradability and biocompatibility, these bio-based plastic products are intended to take the place of traditional plastics in an environmentally responsible and sustainable manner. It is crucial to evaluate the genetic makeup, variety, and end products of bacteria that create PHAs in order to achieve this goal (Vicente et al., 2023).

For the best growth and metabolism, microorganisms need a variety of micronutrients in the right amounts in their ideal growing medium. While trace elements like sulphur, phosphate, vitamins, and so on are micronutrients, carbon and nitrogen are the main sources for microbial development. Additionally, natural medium has long been used as a source for microbial propagation. Because the little salted media is where PHA-producing bacteria are cultivated. 95% water, 4% sugars, 0.1% fat, 0.02% calcium, 0.01% phosphorus, 0.5% iron, significant amounts of amino acids, mineral salts, vitamin B complex, vitamin C, and cytokines make up Tender Coconut Water (TCW), the liquid endosperm found in the coconut fruit's cavity. These nutrients may also provide similar favourable conditions for the growth of bacteria that produce PHAs (Sekar et al., 2013).

It has been established that bacteria are capable of growing in tender coconut water. However, limited information is available regarding the extraction of polyhydroxyalkanoates (PHAs) from coconut rhizosphere soil bacteria cultivated in tender coconut water. Therefore, the present study was undertaken to compare the extraction of PHAs from coconut rhizosphere soil bacteria grown in minimal salt medium (MSM) and tender coconut water (TCW).

II. MATERIALS AND METHODS

2.1 Collection of Soil for bacteria isolation:

Soil samples were collected from agricultural field of coconut *rhizosphere* region, Tumakuru, Karnataka. Sample collected by gently digging them and placed in a sterile polythene bag.(Shraddha et al., n.d.)

2.2 Isolation of bacteria:

The isolation of bacteria was performed by serial dilution method and direct plate technique, using nutrient agar media. Soil sample was serial diluted and placed into nutrient agar plates and incubated at 28℃ for 24 hrs.(Shraddha et al., n.d.)

2.3 Screening for PHA producing bacteria:

Gram's staining was performed to determine whether the bacteria is gram negative or gram positive. The PHAs producing bacteria was confirming by using Sudan black B and Nile blue A staining.(Shraddha et al., n.d.)

2.4 16S rRNA sequencing for Identification of PHA producing Bacteria:

It is a method to identify and characterize bacteria using short, conserved DNA sequences to distinguish different bacterial species within the sample using genetic marker 16S rRNA gene (Mostafa et al., 2020). With the help of MEGA 12 phylogenetic tree was constructed.

2.5 Submerged Cultivation of PHA producing bacteria:

Inoculum of the bacteria was performed by preparing suspension broth using nutrient broth. Further, the suspension broth was inoculated in the minimal salt media which was incubated for a week at 37℃. This media helps to grow PHAs producing bacteria.

Coconut water is used as source of media to grow PHAs producing bacteria. The coconut water is autoclaved under 120°c allowed to cool down and then 5ml of fresh bacterial inoculum is added to the sterilized coconut water and kept for incubation in incubator at 35°c for 7 days.

2.6 Extraction of PHA from cultivated bacteria:

Extraction process was performed by centrifuged the above media like MSM (minimal salt media) and sterilized coconut water media at 7000rpm, 4℃ for 15 mins. Collect the pellet to add 5 ml distilled water. The mixture was sonicated for 30 mins. To that add 5ml of 20% sodium hypochlorite, the mixture was placed on the shaker to get continuous mixing at 150 rpm for 15 mins and incubated for 30mins at 37℃. Again, centrifuge it under 7000rpm at 4℃ for 15mins. The pellet was collected and washed by using acetone: alcohol mixture in the ratio of 1:1 v/v , dissolved the mixture in 10 ml chloroform and placed it at room temperature to get PHAs.(Ibrahim et al., 2025).

2.7 Quantification of PHA by Crotonic acid assay:

The extract (of both sample A which was extracted from MSM and sample B as PHAs extracted from Coconut tender water) was transferred to a clean test tube, and to that add 10 ml of 36N sulfuric acid, capped and heated for 20min at 100℃ in a boiling water bath. Where PHA granules were converted into crotonic acid by dehydration. The resultant, brown-colored solution of crotonic acid was cooled and mixed thoroughly by shaking. The absorbance of the sample was measured at 235nm using a UV-Visible spectrophotometer using sulfuric acid as a control (Ibrahim et al., 2025).

2.8 Biofilm production:

For the preparation of biofilm, two solutions were used, solution A consisted of PHA dissolved in distilled water and solution B consisted of gelatin and agar in 50ml of distilled water, which were separately prepared. Both the solutions were autoclaved at 15lbs of pressure for 15 mins. Later, the solutions were mixed thoroughly with the addition of 2% glycerol and kept it on the magnetic stirrer at 70℃ at 1200 rpm for 20 min. The froth was allowed to settle, and the solution was casted on a glass plate. The obtained biofilm was allowed to dry in a hot air oven at 40℃ for 36h.

2.9 Antioxidant activity:

DPPH assay: The PHAs solution was prepared in condition of 1mg/ml. In test tubes add different Concentration of PHAs solution, dissolve 800 µl of 0.1 M tris-HCL buffer (pH 7.4) and 1 ml of the DPPH solution. In the blank well, add 1.2 ml of ethanol and 800 µl of tris-HCL buffer. Then mix immediately for 10 sec and keep it at room temperature in the dark. After 30min, measure the absorbance of the solution at 517nm.

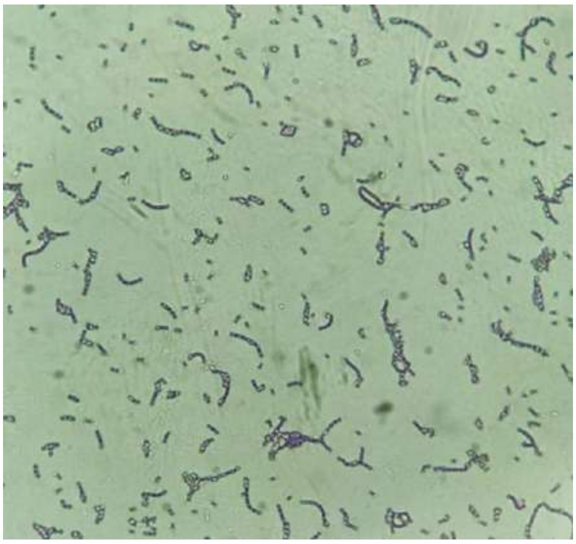
$$\text{I}nhibition\ ratio\ (\%) = \{(Ac - As)/Ac\} * 100 \quad (1)$$

Where Ac is the absorbance of blank and as is the absorbance in presence of the test sample.(Mahayothee et al., 2016).

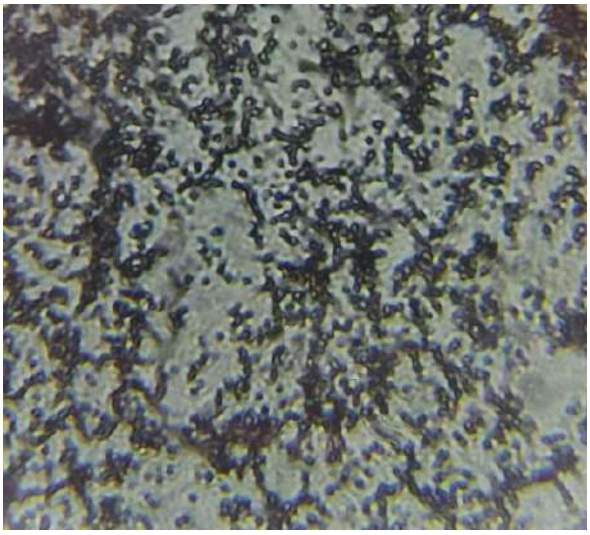
III. RESULT AND DISCUSSION

The presence of PHA-producing bacteria was initially determined using Sudan Black B staining. Sudan Black B is a lysochrome, a fat-soluble dye, commonly employed to detect intracellular lipid inclusions. In PHA-producing bacteria, staining with Sudan Black B results in a distinct black coloration, indicating the presence of PHAs. PHAs are biopolymers composed of hydroxyalkanoate monomers, possessing a lipid-like structure. Being a lipophilic dye, Sudan Black B specifically binds to lipids and other hydrophobic molecules within the cell, making it a useful preliminary screening agent for lipophilic compounds. The PHA granules were identified based on their strong affinity for Sudan Black B, as reported by Ostle and Holt.

Confirmation of PHA production was performed using Nile Blue A staining. Nile Blue A is a basic oxazine dye, soluble in both water and ethyl alcohol, and is known for its ability to stain PHAs within microbial cells. At the staining temperature of 55 °C, Nile Blue A readily dissolves in neutral lipids, which are in a liquid state, and selectively binds to the hydrophobic PHA granules within bacterial cells. This hydrophobic interaction allows Nile Blue A to serve as a reliable confirmatory stain for PHA-accumulating microorganisms, as described by Ostle and Holt.



(a)



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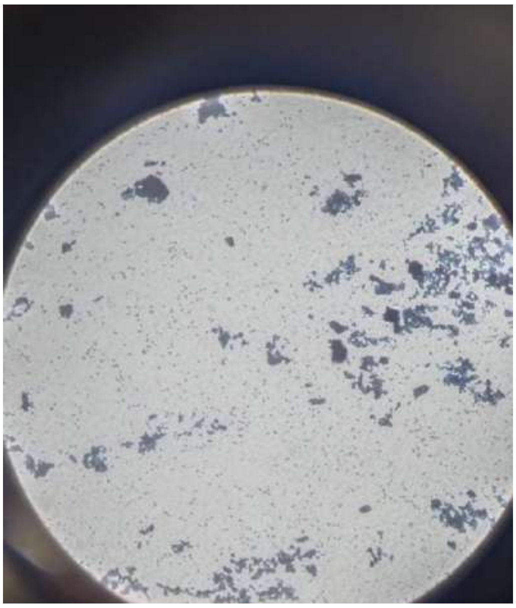


(c)

(d)

FIGURE 1: (a) Screening for PHAs producing bacteria - gram positive and rod shaped under microscope 40X. Figure 1(b) and (c) indicates PHAs producing Bacteria by Staining with Sudan Black B and Nile Blue A respectively observed under the microscope 40X. Figure 1 (d) pure culture of the PHAs producing bacteria.

3.1 Extraction of PHA from MSM and TCW:

The successful extraction of PHAs was indicated by the presence of a white, powdery residue after solvent evaporation, characteristic of PHA polymers. This visual confirmation strongly supports the presence of intracellular PHA granules within the bacterial cells grown in MSM and TCW.

The PHAs accumulation (%) in the sample A:

= Dry weight of extracted PHAs (mg/ml)/Dry cell weight (mg/ml) X 100

PHAs accumulation (%) = **1325.5**(mg/ml)/**2426**(mg/ml) X100

= **54.637%**

The PHAs accumulation of sample A from the Extracted PHAs by sodium hypochlorite method and using chloroform as solvent was **54.637%.**

The PHAs accumulation (%) in the sample B:

= Dry weight of extracted PHAs (mg/ml)/Dry cell weight (mg/ml) X 100

PHAs accumulation (%) = **138**(mg/ml)/**245**(mg/ml) X100

= **56.326%**

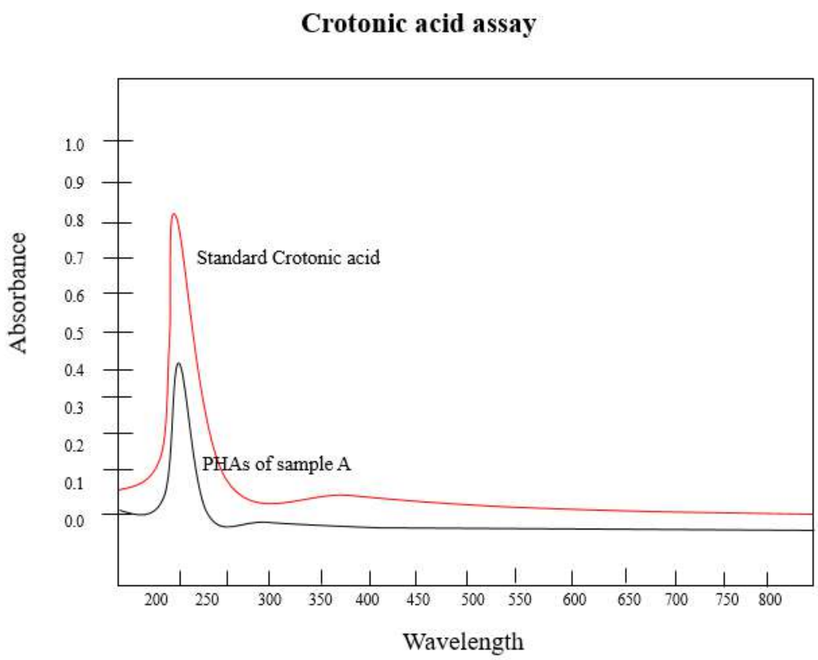
The PHAs accumulation of sample B from the Extracted PHAs by sodium hypochlorite method and using chloroform as solvent was **56.326%.**

3.2 Quantification of the PHA by crotonic acid assay:

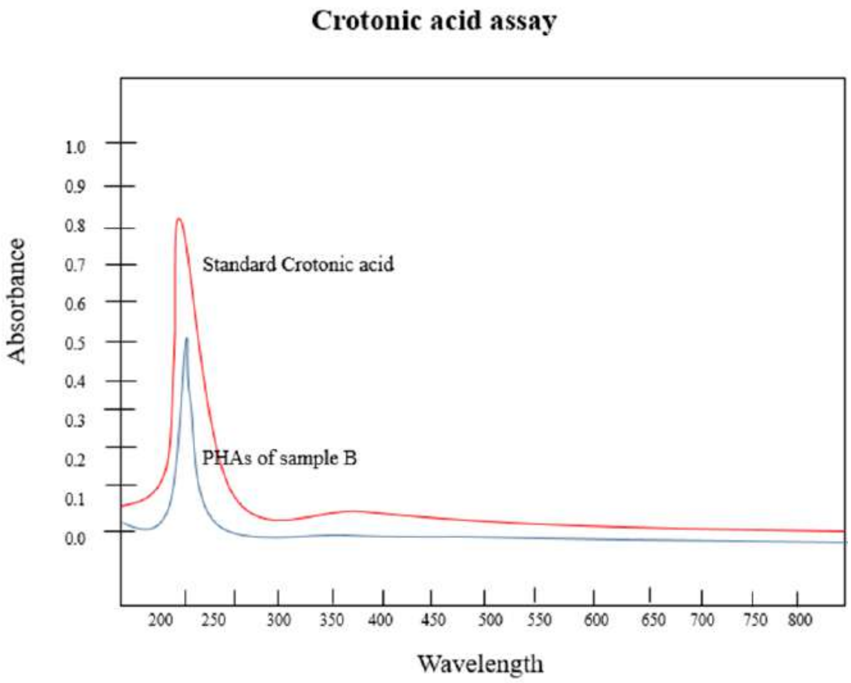
Figure 2 shows the UV-Vis absorption spectra of the extracted PHA sample A (black line) & Sample B (Blue Line) compared with standard crotonic acid (red line), measured across a wavelength range of 200–800 nm. Both the standard and the samples exhibited a prominent absorption peak at approximately 235 nm, which is a characteristic wavelength for crotonic acid, a product formed upon acid digestion of PHA.

The PHA samples showed a similar absorbance profile to that of the standard crotonic acid, confirming the presence of PHA in the bacterial extract. Although the absorbance intensity of the sample was lower than that of the standard, the peak position at 235 nm suggests that the extracted compound is structurally consistent with crotonic acid, indicating successful PHA production and extraction.

The difference in peak intensity may be attributed to variations in concentration, partial digestion, or differences in extraction efficiency. Nonetheless, the similarity in spectral behavior between the extracted PHA and the crotonic acid standard validates the presence of PHA in the tested bacterial culture.

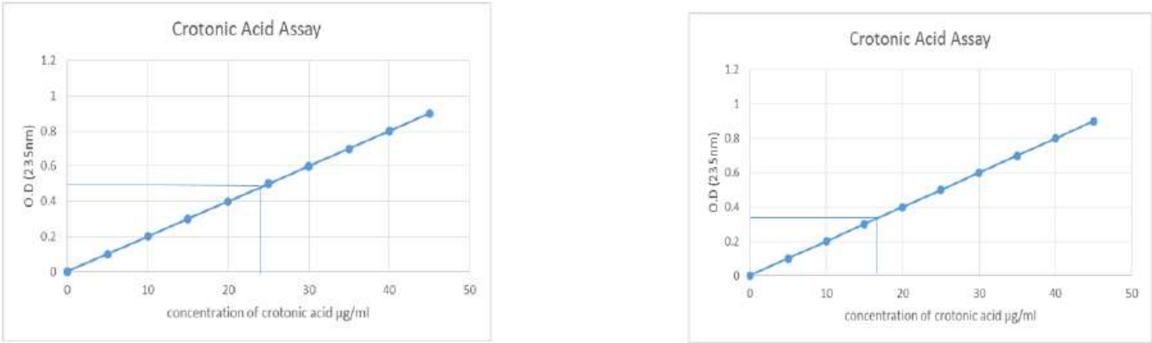


(a)



(b)

FIGURE 2: (a) The UV-Vis spectra illustrate the absorbance peaks of the standard crotonic acid (indicated by red line) and PHAs granules of sample A (indicated by grey line) at a Wavelength of 235nm. (b) The UV-Vis spectra illustrate the maxima absorbance peaks of the standard crotonic acid (indicated by red line) and PHAs granules of sample B (indicated by blue line).



(a) **(b)**

FIGURE 3: (a) The concentration of the PHAs using Standard crotonic acid for the sample A. (b) the concentration of the PHA using standard crotonic acid for the sample B.

Figure 3 illustrates the standard calibration curve generated for crotonic acid, based on absorbance measurements taken at 235 nm. The graph shows a linear relationship between the concentration of crotonic acid (µg/mL) and optical density (OD) at 235 nm, with increasing absorbance corresponding to increasing concentrations of crotonic acid. This linearity confirms the suitability of the assay for quantifying PHA content via acid digestion, wherein PHA were converted to crotonic acid.

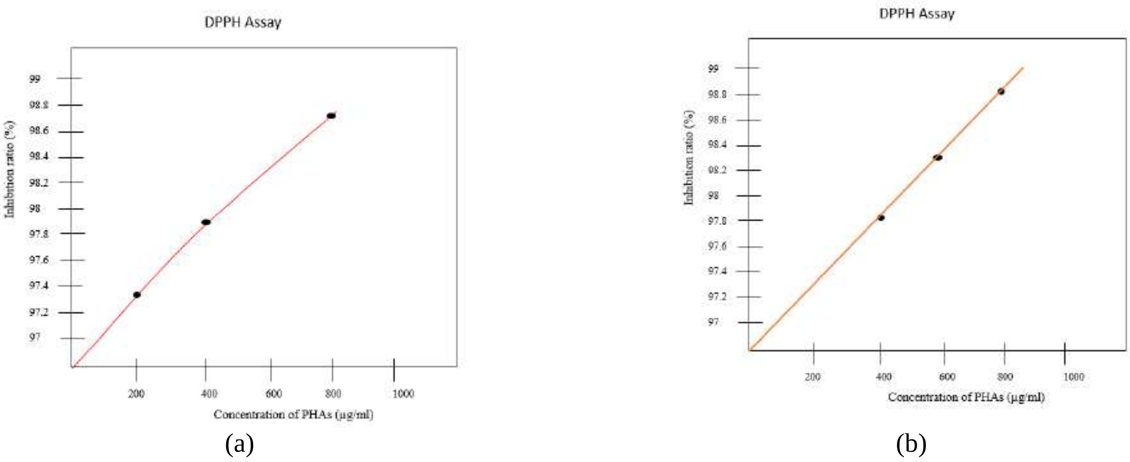
Using this calibration curve, the PHA content in the experimental samples was determined. The absorbance value for the sample A was approximately **0.48**, which corresponds to a crotonic acid concentration of roughly **24 µg/mL** based on the plotted trend line Fig 3 (a) and the absorbance value for the sample B was approximately **0.36**, which corresponds to a crotonic acid concentration of roughly **15 µg/mL** based on the plotted trend line Fig 3 (b). This concentration reflects the amount of crotonic acid derived from the acid digestion of the extracted PHA, and by extension, provides an indirect quantification of PHA content in the bacterial culture.

3.3 Antioxidant Activity by DPPH Assay:

Figure 4 illustrates the antioxidant activity of extracted PHA as determined by the DPPH (2,2-diphenyl-1-picrylhydrazyl) radical scavenging assay. The inhibition ratio (%) was plotted against different concentrations of PHAs (µg/mL), showing a clear dose-dependent antioxidant effect.

As the concentration of PHAs increased from 200 µg/mL to 800 µg/mL, the DPPH inhibition ratio also increased from approximately **97.2% to 98.6% for Sample A and for Sample B 97.8% to 98.8%**, indicating strong free radical scavenging activity. The observed trend suggests that the extracted PHA possesses intrinsic antioxidant potential.

The nearly linear increase in inhibition ratio with concentration demonstrates that the antioxidant activity of PHAs is both consistent and effective, although the changes are relatively small due to the high baseline inhibition. These findings indicates that PHA, beyond their biopolymer applications, may also exhibit bioactive properties, potentially useful in biomedical or packaging industries where oxidative stability was desired.



(a) (b)

FIGURE 4: The UV-Vis spectra readings exhibit the inhibition ratio at the absorbance 517nm for the sample A in (a) and for sample B in (b).

IV. CONCLUSION

The findings of this study demonstrate that PHAs, which are polyesters accumulated in microorganisms, have the potential to serve as raw materials for the production of bioplastics. Enhancing the production of PHA-based bioplastics could promote their use as an environmentally friendly alternative to conventional plastics, which contribute significantly to environmental pollution and harm to wildlife. The replacement of plastics with biodegradable PHAs would reduce environmental contamination and, when disposed of in soil, could even enhance soil fertility. PHA-based bioplastics are eco-friendly, generate zero waste, and are user-friendly, making them a sustainable option for the future.

In conclusion, the rhizosphere bacterium *Bacillus anthracis* was found to produce PHA polyesters possessing desirable characteristics for bioplastic production. These PHAs exhibited antioxidant activity, as determined by the DPPH assay. The PHA accumulation was measured at 54.637% in Sample A (cultivated in minimal salt medium) and 56.326% in Sample B (cultivated in sterilized tender coconut water). The higher yield in Sample B suggests that tender coconut water can serve as a cost-effective and sustainable raw material for large-scale PHA production. Future studies should investigate the characteristics of PHA-based biofilms and their degradability under real-world conditions, which could further enhance their potential as sustainable materials.

REFERENCES

[1] Acharjee, S. A., Bharali, P., Gogoi, B., Sorhie, V., Walling, B., & Alemtoshi. (2023). PHA-Based Bioplastic: A Potential Alternative to Address Microplastic Pollution. Water, Air, and Soil Pollution, 234(1), 21. https://doi.org/10.1007/s11270-022-06029-2

[2] Sekar, N., Veetil, S. K., & Neerathilingam, M. (2013). Tender coconut water an economical growth medium for the production of recombinant proteins in Escherichia coli. BMC Biotechnology, 13, 70. https://doi.org/10.1186/1472-6750-13-70

[3] Song, J. H., Murphy, R. J., Narayan, R., & Davies, G. B. H. (2009). Biodegradable and compostable alternatives to conventional plastics. Philosophical Transactions of the Royal Society B: Biological Sciences, 364(1526), 2127–2139. https://doi.org/10.1098/rstb.2008.0289

[4] Vicente, D., Proença, D. N., & Morais, P. V. (2023). The Role of Bacterial Polyhydroalkanoate (PHA) in a Sustainable Future: A Review on the Biological Diversity. International Journal of Environmental Research and Public Health, 20(4), 2959. https://doi.org/10.3390/ijerph20042959.

[5] Shah, S., & Kumar, A. (2021). Production and characterization of polyhydroxyalkanoates from industrial waste using soil bacterial isolates. Brazilian Journal of Microbiology, 52(2), 715–726. https://doi.org/10.1007/s42770-021-00452-z

[6] Ibrahim, R., Aranjani, J. M., Prasanna, N., Biswas, A., & Gayam, P. K. R. (2025). Production, isolation, optimization, and characterization of microbial PHA from Bacillus australimaris. Scientific Reports, 15, 8395. https://doi.org/10.1038/s41598-025-92146-x

[7] Shraddha, G., Yogita, R., Simanta, S., Aparna, S., & Kamlesh, S. (n.d.). Screening and production of bioplastic (PHAs) from sugarcane rhizospheric bacteria.

[8] Desiante, W. L., Carles, L., Wullschleger, S., Joss, A., Stamm, C., & Fenner, K. (2022). Wastewater microorganisms impact the micropollutant biotransformation potential of natural stream biofilms. Water Research, 217, 118413. https://doi.org/10.1016/j.watres.2022.118413

[9] Mostafa, Y. S., Alrumman, S. A., Otaif, K. A., Alamri, S. A., Mostafa, M. S., & Sahlabji, T. (2020). Production and Characterization of Bioplastic by Polyhydroxybutyrate Accumulating Erythrobacter aquimaris Isolated from Mangrove Rhizosphere. Molecules, 25(1), Article 1. https://doi.org/10.3390/molecules25010179

[10] Mirpoor, S. F., Patanè, G. T., Corrado, I., Giosafatto, C. V. L., Ginestra, G., Nostro, A., Foti, A., Gucciardi, P. G., Mandalari, G., Barreca, D., Gervasi, T., & Pezzella, C. (2023). Functionalization of Polyhydroxyalkanoates (PHA)-Based Bioplastic with Phloretin for Active Food Packaging: Characterization of Its Mechanical, Antioxidant, and Antimicrobial Activities. International Journal of Molecular Sciences, 24(14), Article 14. https://doi.org/10.3390/ijms241411628

[11] Oliveira, G., Petronilho, S., Kapusniak, K., Kapusniak, J., del Castillo, M. D., Coimbra, M. A., Ferreira, P., Passos, C. P., & Gonçalves, I. (2024). Antioxidant and flexible bioplastics based on microwave-assisted extracted coffee fruit cascara pectic polysaccharides. Journal of Cleaner Production, 453, 142264. https://doi.org/10.1016/j.jclepro.2024.142264

[12] Hassan, S., Khudur, L. S., Nahar, K., Dekiwadia, C., & Ball, A. S. (2025). Isolation and Identification of Xylose-Utilising, Polyhydroxyalkanoate-Producing Bacteria from Sugarcane Bagasse: First Report of PHA Production by Mycolicibacterium Smegmatis. Journal of Polymers and the Environment. https://doi.org/10.1007/s10924-025-03600-w

Changes in Occupational Structure of Population in Jashpur District (C.G.): A Geographical Study

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Abstract— *Occupational structure of the population refers to the distribution of the working population across different sectors of the economy, which essentially indicating what proportion of people are employed in different types of work. It is a major indicator of a country's economic development as well as its level of industrialization. The changing pattern of occupational structure depends primarily on various interrelated factors, including the level of economic development, educational attainment and technological advancements etc. The study area Jashpur district lies in the North-eastern corner of Chhattisgarh State with latitudinal and longitudinal extension is 22^0 17' to 23^0 15' North and 83^0 30' to 84^0 24' East respectively. The present paper focus on the changes in occupational structure of population in Jashpur district from 2001 to 2011. This paper is based on secondary data which collected from the District Census Handbook 2001 & 2011of Jashpur. The main findings are that the occupational structure in Jashpur district is rapidly changing, as most people are moving away from traditional agricultural practices towards a more diversified economy, characterized by a significant decline in the proportion of main workers and an increase in marginal workers as well as a decrease in the overall working population.*

Keywords— Jashpur district, Occupational structure, Main workers, Marginal workers and Non-workers Population.

I. INTRODUCTION

Occupational structure is the distribution or division of working population in different sectors based on occupations. It is one of the key elements in manifestation of population composition of a region [**3**]. Occupational structure is playing an important role in the socio-economic activities in the region. It is one of the most significant social features that impacts human life [**4**]. The study of occupational structure of the population is an important tool that assesses the ratio of the entire working and non-working population and presents a clear picture of its entire work force [**5**]. The socio-economic development of any regions depends on the number of individuals who are economically active and it is one aspect of population structure which shows how the population is engaged in various economic activities [**6**]. The occupational changes of a nation refer to the percentage of its work force employed in various economic activities [**10**]. An analysis of working force provides a useful tool to the social scientists not only for measuring the level of social and economic development an area has attained but also for formulating future plans for mobilizing its man power [**8**].

II. MATERIALS AND METHOD

2.1 Study Area:

Jashpur, located on the western extension of Chhotanagpur Plateau and it is lies in the North-eastern corner of Chhattisgarh State adjoining the borders of Jharkhand and Odisha States in the eastern side. It extends from 22^0 17' to 23^0 15' on North latitude and 83^0 30' to 84^0 24' East longitude. The total area of the district is 5837.75 sq. km. Jashpur Nagar is the District Headquarter. Administratively, the district is divided into 8 CD-Blocks. The decadal growth rate of population of the district is 14.6 percent (Census - 2011). Jashpur district recorded highest work participation rate of 57.2 percent and occupies top position in the State.

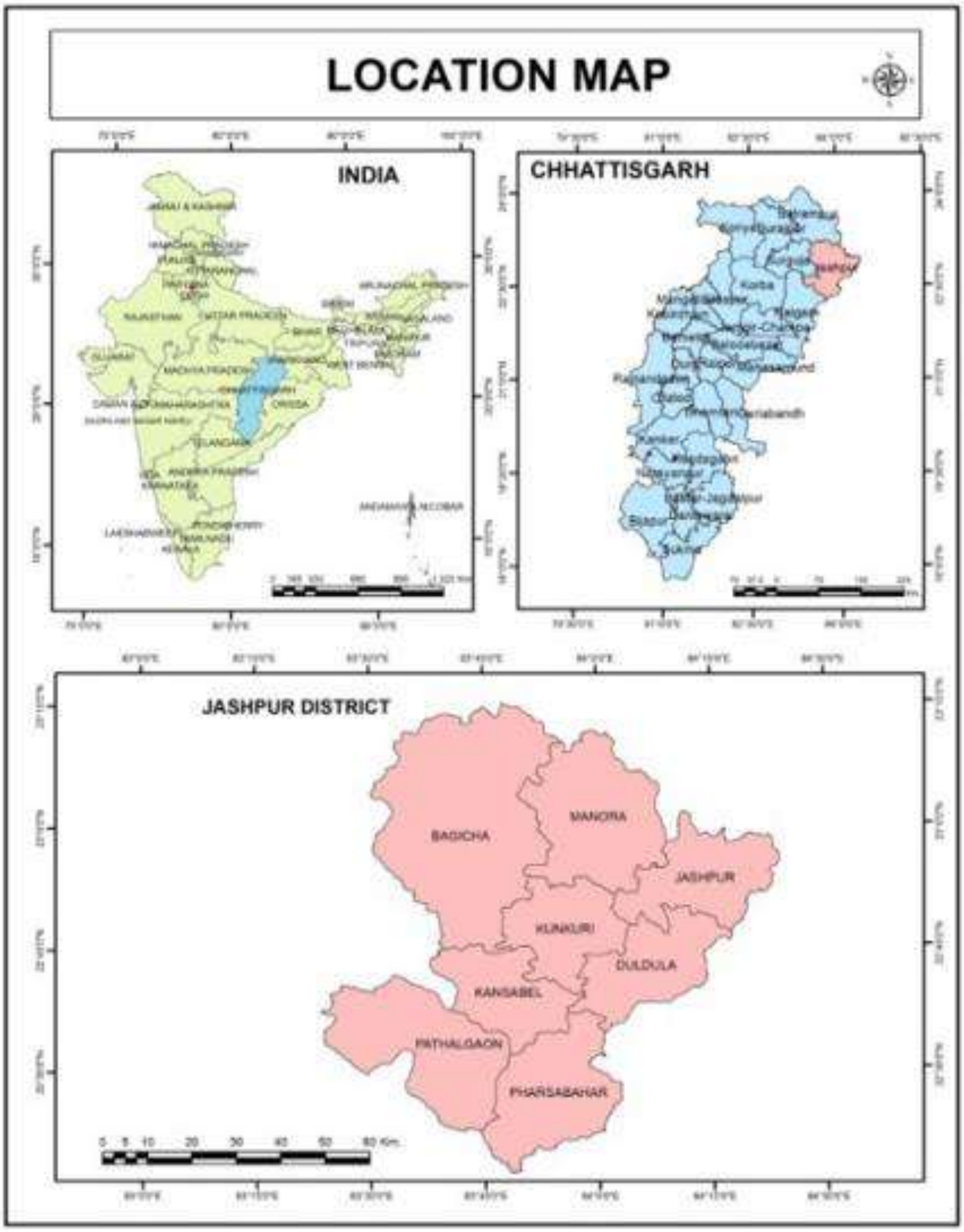

FIGURE 1: location map of the study area.

2.2 Objectives of the Study:

The main objectives of the study are as follows –

a) To understand the changing pattern of occupational structure in Jashpur district from 2001 to 2011.
b) To study the causes of spatial variation and change in occupational structure.

2.3 Database and Methodology:

The Present study is based on Secondary data to describe occupational changes and a meaningful cartographic presentation of all aspects. The secondary data has been collected from the district census handbook 2001 & 2011 of Jashpur. The data analysis has been done on computer with the help of statistical techniques and systematically represented through the cartographic techniques by Arc GIS software as well as using various diagrams to make a significant interpretation of different aspects of the study.

III. RESULTS AND DISCUSSIONS

3.1 Occupational Profile of the Study area:

The occupational structure of Jashpur district is predominantly agrarian based, with a large portion of the population engages in agriculture and related activities. The district's economy is largely agro-based, with a significant rural population relying on agriculture for their livelihood. The primary occupation in Jashpur is agriculture, with paddy being the principle crop. The study area has not seen significant industrial growth and there is a noticeable increase in service enterprises [**2**].

3.2 Major Categories of Occupational structure in Jashpur District:

The working population is the population engaged in the work of production. The working population plays an important role in determining the social and economic status of a particular region [**11**]. The higher proportion of the working population denotes the economic development of that region, the living standard of the people and quality of life in that region [**1**]. In Jashpur district, the workforce is generally categories into total workers (employed persons) & non-workers (not in the labor force) which are based on the various economic activities of the study area.

3.2.1 Total Workers population (Main + Marginal Workers):

The total workers population can be calculated by adding the number of employed people to the number of unemployed people (actively seeking work). According to census 2001, the total workers population of the study area is 387895 (54.70 %) persons whereas male's total workers are 205688 (58.10 %) persons and female's total workers are 182207 (51.30 %) persons. While in census 2011, the total workers population of the study area is 487360 (57.22 %) persons whereas male's total workers is 263645 (62.07 %) persons and female's total workers is 223715 (52.40 %) persons, which is shown in the table no. 01 & fig. no. 02.

a) Main Workers:

A person who has worked for the major part of the reference period (i.e. six months or more during the last one year preceding the date of enumeration) in any economically productive activity is termed as the main workers population. According to census 2001 the main workers population of the study area is 253084 persons (35.70 %) whereas male's main workers is 175412 persons (49.60 %) and female's main workers is 77672persons (21.90 %). On the other hand, in census 211 the main workers population of the study area is 291349 persons (34.21 %) whereas male's main workers is 199035 persons (46.86 %) and female's main workers is 92314 persons (21.62 %), which is shown in the table no. 03.

b) Marginal Workers:

A person who worked for 3 months or less but less than six months of the reference period (i.e. in the last one year preceding the date of enumeration) in any economic activity is termed as Marginal worker. According to census 2001, the marginal workers population of the study area is 134811 persons (19.00 %) whereas male's marginal workers is 30276 persons (8.60 %) and female's marginal workers is 104535 persons (29.40 %). The marginal workers population of the study area is 196011 persons (23.01 %) whereas male's marginal workers is 64610 persons (15.21 %) and female's marginal workers is 131401 persons (30.78 %) in census 2011, which is shown in the table no. 03.

3.2.2 Non-Workers Population:

The term non-workers in a population refer to individuals who are not classified as either employed or unemployed, meaning they are not part of the labor force. The non-working population can be calculated by subtracting the labor force from the total population. According to census 2001, the non-workers population of the study area is 321070 persons (45.30 %) whereas male's non-workers is 148189 persons (41.90 %) and female's non-workers is 172881 persons (48.70 %). On the other hand in census 2011, the non-workers population of the study area is 364309 persons (42.78 %) whereas male's non-workers is 161102 persons (37.93 %) and female's non-workers is 203207 persons (47.60 %), which is shown in the table 1 & fig. 2.

TABLE 1
JASHPUR DISTRICT: DECADAL CHANGE IN BETWEEN TOTAL WORKERS AND NON-WORKERS POPULATION

Population Types	Persons / Males / Females	Jashpur District					
		Numbers			Percentage (%)		
		Census 2001	Census 2011	Decadal Change 2001-11	Census 2001	Census 2011	Decadal Change 2001-11
Total Workers (Main & Marginal workers) Population	Persons	387895	487360	+ 99465	54.70	57.22	+ 2.52
	Males	205688	263645	+ 57957	58.10	62.07	+ 3.97
	Females	182207	223715	+ 41508	51.30	52.40	+ 1.10
Non - Workers population	Persons	321070	364309	+ 43239	45.30	42.78	- 2.52
	Males	148189	161102	+ 12913	41.90	37.93	- 3.97
	Females	172881	203207	+ 30326	48.70	47.60	- 1.10

Source: District Census Handbook - 2001 & 2011, Jashpur district (C.G.).

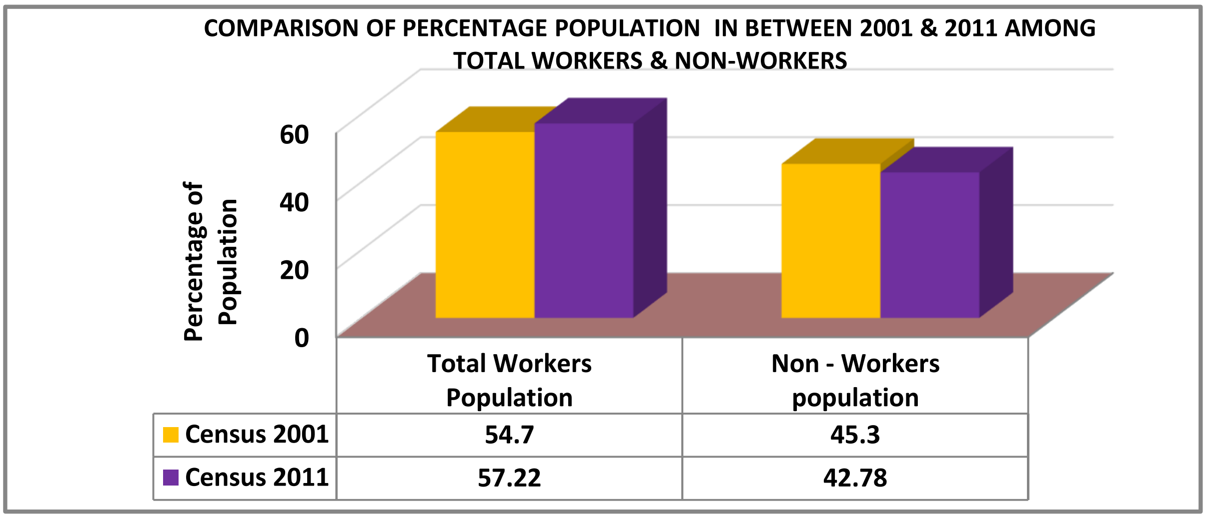

FIGURE 2: Comparison of percentage population in between 2001 & 2011 among total workers & non-workers.

3.3 Distribution of Workers in Four Categories of Economic Activity in Jashpur District:

Man has been active for thousands of years for his basic needs - Foods, Shelter and Clothing. Population characteristics of any region are justified by its occupational structures which are mainly depends on various economic activities [**7**]. The study of various economic elements of population is not possible to explain without an Occupational structure [**12**]. Occupational structure of the region is correlated to educational levels and income status of the society [**9**]. In the study area, the distribution of workers can be divided into four major categories of economic activity which as cultivators, agricultural labourers, household industry workers and other workers.

3.3.1 Cultivators:

Cultivators defined the people engaged in agriculture as well as it can be farmers who prepare land for planting and grow crops. According to census 2001, the cultivators of the study area is 248672 persons (64.10 %) whereas male cultivators is 137926 persons (67.10 %) and female cultivators is 110746 persons (60.80 %). On the other hand, the cultivators of the study area is 226866 persons (46.55 %) whereas male cultivators is 132527 persons (50.27 %) and female cultivators is 94339 persons (42.17 %) in census 2011.

3.3.2 Agricultural Labourers:

Agricultural labourers are individuals who work in agriculture for wages, either in cash of kind, often on land owned by others. According to census 2001, the agricultural labourers of the study area is 99468 persons (25.60 %) whereas male's agricultural labourers is 39609 persons (19.30 %) and female's agricultural labourers is 59859 persons (32.90 %). On the other hand, in census 2011 the agricultural labourers of the study area is 197558 persons (40.54 %) whereas male's agricultural labourers is 87854 persons (33.32 %) and female's agricultural labourers is 109704 persons (49.04 %).

3.3.3 Household Industry Workers:

Household industry workers are individuals engaged in economic activities within their own homes or within the village or household premises in urban areas, primarily focused on production, processing, servicing or repairing of goods. According to census 2001, the household industry workers of the study area is 10388 persons (2.70 %) whereas male household industry workers is 5939 persons (2.90 %) and female household industry workers is 4449 persons (2.40 %). While in census 2011, the household industry workers of the study area is 7553 persons (1.55 %) whereas male household industry workers is 4315 persons (1.64 %) and female household industry workers is 3238 persons (1.45 %).

3.3.4 Other Workers:

In the context of economic activity, other workers refer to individuals who are engaged in economic production but are not considered part of the traditional employee. According to census 2001, the other workers of the study area is 29367 persons (7.60 %) whereas male other workers is 22214 persons (10.80 %) and female other workers is 7153 persons (3.90 %). Whereas in census 2011, the other workers of the study area is 55383 persons (11.36 %) whereas male other workers is 38949 persons (14.77 %) and female other workers is 16434 persons (7.35 %), which is shown in the table 2.

TABLE 2
DISTRIBUTION OF WORKERS & DECADAL CHANGE FROM 2001 TO 2011 IN FOUR CATEGORIES OF ECONOMIC ACTIVITY

Category of Workers	Persons / Males / Females	Numbers of population			Percentage (%) of population		
		Census 2001	Census 2011	Decadal Change 2001-11	Census 2001	Census 2011	Decadal Change 2001-11
Cultivators	Persons	248672	226866	- 21806	64.10	46.55	- 17.55
	Males	137926	132527	- 5399	67.10	50.27	- 16.83
	Females	110746	94339	- 16407	60.80	42.17	- 18.63
Agricultural labourers	Persons	99468	197558	+ 98090	25.60	40.54	+ 14.94
	Males	39609	87854	+ 48245	19.30	33.32	+ 14.02
	Females	59859	109704	+ 49845	32.90	49.04	+ 16.14
Household Industry Workers	Persons	10388	7553	- 2835	2.70	1.55	- 1.15
	Males	5939	4315	- 1624	2.90	1.64	- 1.26
	Females	4449	3238	- 1211	2.40	1.45	- 0.95
Other workers	Persons	29367	55383	+ 26016	7.60	11.36	+ 3.76
	Males	22214	38949	+ 16735	10.80	14.77	+ 3.97
	Females	7153	16434	+ 9281	3.90	7.35	+ 3.45

Source: District Census Handbook - 2001 & 2011, Jashpur district (C.G.).

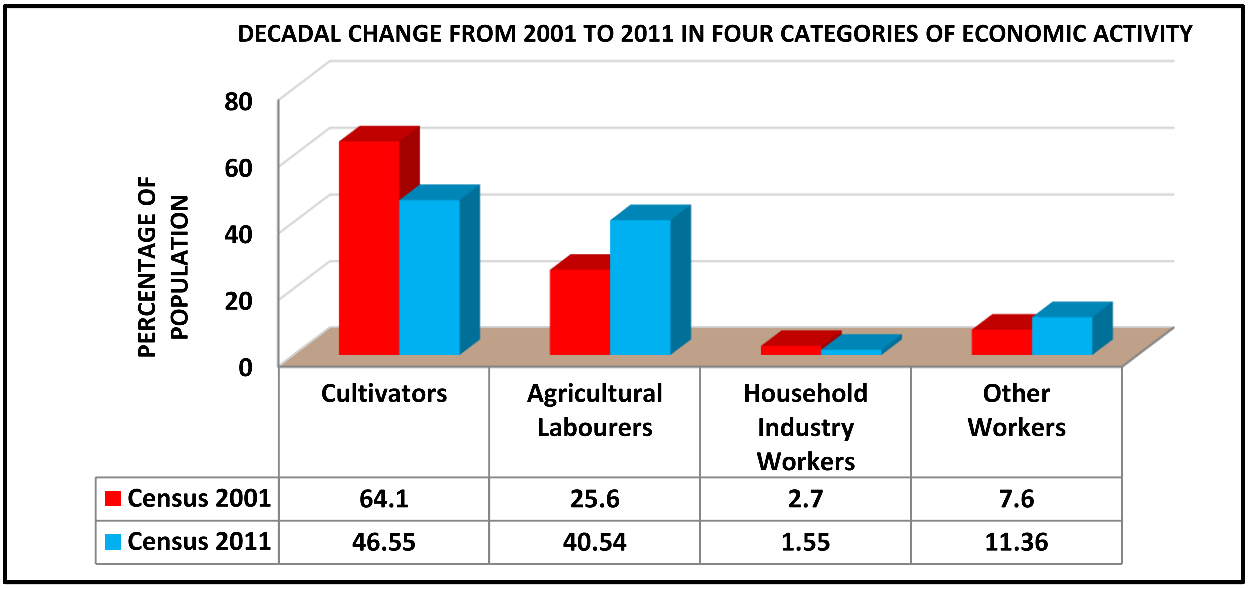

FIGURE 3: Decadal change from 2001 to 2011 in four categories of economic activity.

3.4 Decadal change from 2001 to 2011 in Occupational structures of Jashpur district:

3.4.1 Decadal Change in total workers population (Main + Marginal workers):

The decadal change of main workers was - 1.49 % from 2001 to 2011 in Jashpur district which indicate the decreasing trend of main workers in percentage due to a shift from agricultural labor to other forms of work or a decrease in the overall population engaged in manual labor, While the total workers population of Jashpur district increased (+ 2.52 %) during this period. The decadal change of marginal workers was + 4.01 % from 2001 to 2011 in the study area which witnessed a positive growth in percentage due to a combination of factors including population growth, changes in economic conditions, and possibly evolving definitions of classifications of marginal workers in census data, which is shown in the table 3 & fig. 4.

Under the category of total workers population (main + marginal workers) the high positive decadal change has been found in CD-Block Manora (+ 12.17 %) from 2001 to 2011 in the study area due to a combination of factors including overall population growth and potential shifts in the workforce structure. While the high negative decadal change has been found in CD-Block Jashpur (- 4.65 %) from 2001 to 2011 in the study area due to a combination of various factors such as slower growth in the overall population compared to the previous decade and possibly shifts in economic activities, which is shown in the table 4 & fig. 5.

3.4.2 Decadal Change in Non-Workers population:

The decadal change of non-workers population was - 2.52 % from 2001 to 2011 in Jashpur district which indicate the negative growth in percentage due to a combination of different factors such as increased access to education, improve healthcare, and a shift in economic opportunities. These factors may have led to more people transitioning into the workforce or becoming dependent on others for support, which is shown in the table 3 & fig. 4.

Under the category of non-workers population the high positive decadal change has been found in CD-Block Jashpur (+ 4.65 %) from 2001 to 2011 in the study area due to different factors like general increase in the overall population and potentially shifts in the age structure of the population towards a larger proportion of children and elderly individuals who are typically classified as non-workers. While the high negative decadal change has been found in CD-Block Manora (- 12.17 %) from 2001 to 2011 in the study area due to increased economic activity, employment opportunities leading to more people entering the workforce, migration and changes in the age structure of the population, which is shown in the table 4 & fig. 6.

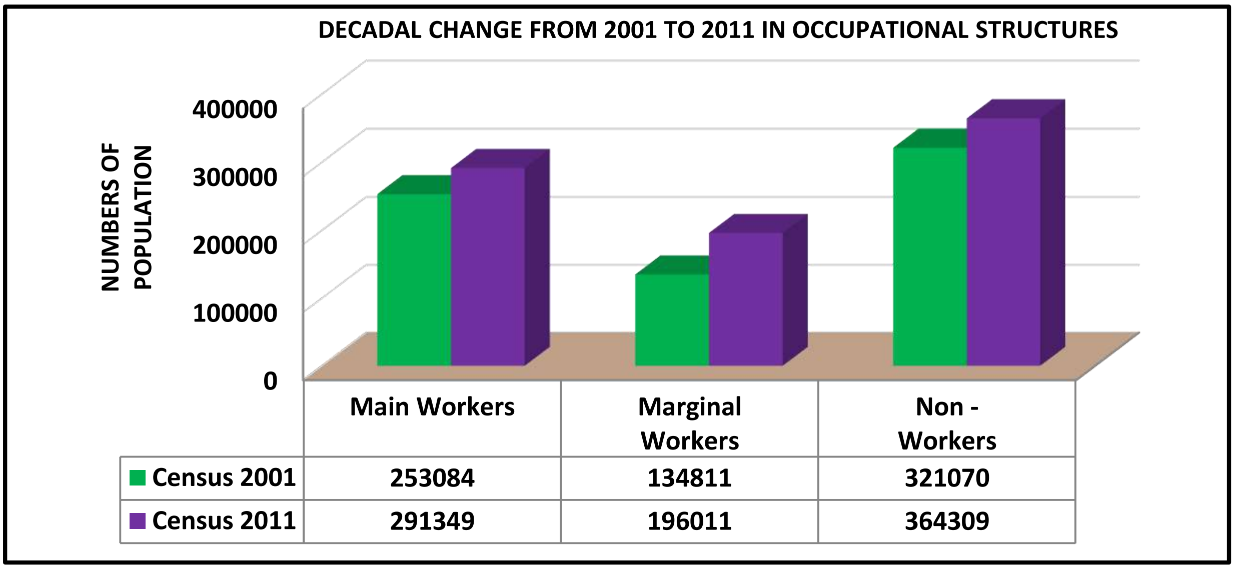

FIGURE 4: Decadal change from 2001 to 2011 in occupational structures.

TABLE 3
DECADAL CHANGE FROM 2001 TO 2011 IN OCCUPATIONAL STRUCTURES

Types of Workers	Persons / Males /Females	Numbers of population			Percentage (%) of population		
		Census 2001	Census 2011	Decadal Change 2001-11	Census 2001	Census 2011	Decadal Change 2001-11
Main Workers	Persons	253084	291349	+ 38265	35.70	34.21	- 1.49
	Males	175412	199035	+ 23623	49.60	46.86	- 2.74
	Females	77672	92314	+ 14642	21.90	21.62	- 0.28
Marginal Workers	Persons	134811	196011	+ 61200	19.00	23.01	+ 4.01
	Males	30276	64610	+ 34334	8.60	15.21	+ 6.61
	Females	104535	131401	+ 26866	29.40	30.78	+ 1.38
Non - Workers	Persons	321070	364309	+ 43239	45.30	42.78	- 2.52
	Males	148189	161102	+ 12913	41.90	37.93	- 3.97
	Females	172881	203207	+ 30326	48.70	47.60	- 1.10

Source: District Census Handbook - 2001 & 2011, Jashpur district (C.G.).

TABLE 4
CD - BLOCK WISE DECADAL CHANGE FROM 2001 TO 2011 IN TOTAL WORKERS AND NON-WORKERS POPULATION

Sl. No.	Name of CD-Blocks	Total Workers population (Main + Marginal workers)						Non-Workers population					
		Numbers			Percentage (%)			Numbers			Percentage (%)		
		Census 2001	Census 2011	Decadal Change 2001-11	Census 2001	Census 2011	Decadal Change 2001-11	Census 2001	Census 2011	Decadal Change 2001-11	Census 2001	Census 2011	Decadal Change 2001-11
01.	Bagicha	87445	105708	+ 18263	59.10	61.56	+ 2.46	60446	66003	+ 5557	**40.90**	**38.44**	- 2.46
02.	Kansabel	41912	43602	+ 1690	60.60	56.82	- 3.78	27298	33133	+ 5835	**39.40**	**43.18**	+ 3.78
03.	Jashpur	34220	49577	+ 15357	56.10	51.45	- 4.65	26790	46783	+ 19993	**43.90**	**48.55**	+ 4.65
04.	Manora	29636	40891	+ 11255	55.20	67.37	+ 12.17	24091	19804	- 4287	**44.80**	**32.63**	- 12.17
05.	Kunkuri	39158	54396	+ 15238	47.50	57.08	+ 9.58	43297	40904	- 2393	**52.50**	**42.92**	- 9.58
06.	Duldula	25248	30093	+ 4845	55.50	59.19	+ 3.69	20228	20747	+ 519	**44.50**	**40.81**	- 3.69
07.	Farsabahar	51357	59582	+ 8225	52.20	54.92	+ 2.72	46995	48916	+ 1921	**47.80**	**45.08**	- 2.72
08.	Pathalgaon	78909	103511	+ 24602	52.30	54.04	+ 1.74	71925	88019	+ 16094	**47.70**	**45.96**	- 1.74
Jashpur District		**387895**	**487360**	**+ 99465**	**54.70**	**57.22**	**+ 2.52**	**321070**	**364309**	**+ 43239**	**45.30**	**42.78**	**- 2.52**

Source: District Census Handbook - 2001 & 2011, Jashpur district (C.G.).

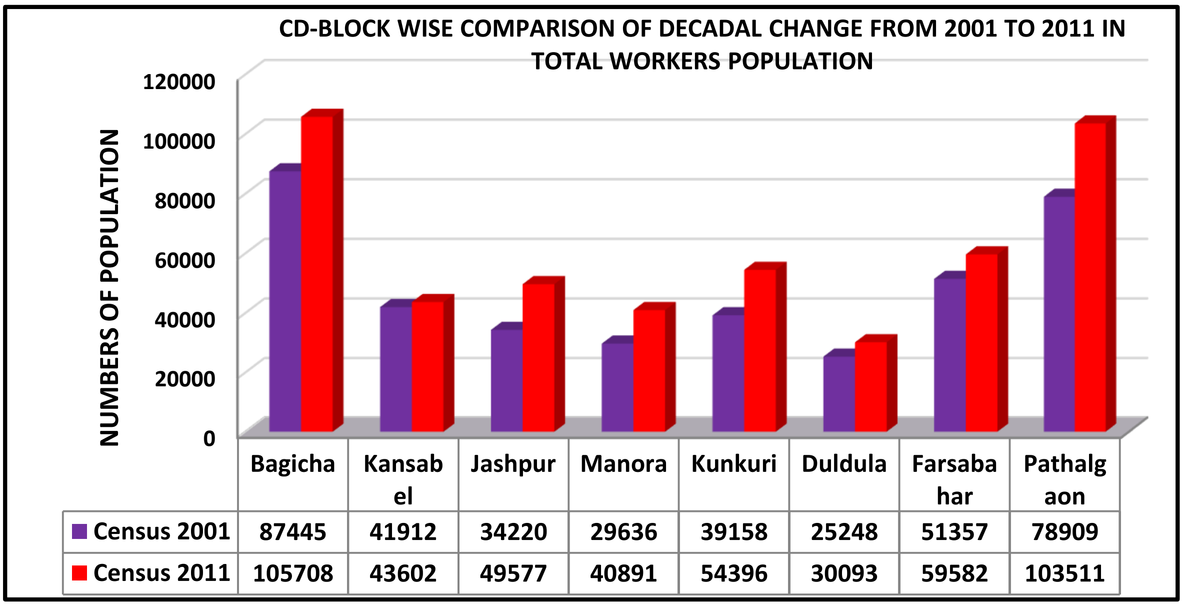

FIGURE 5: CD-Block wise comparison of decadal change from 2001 to 2011 in total workers population.

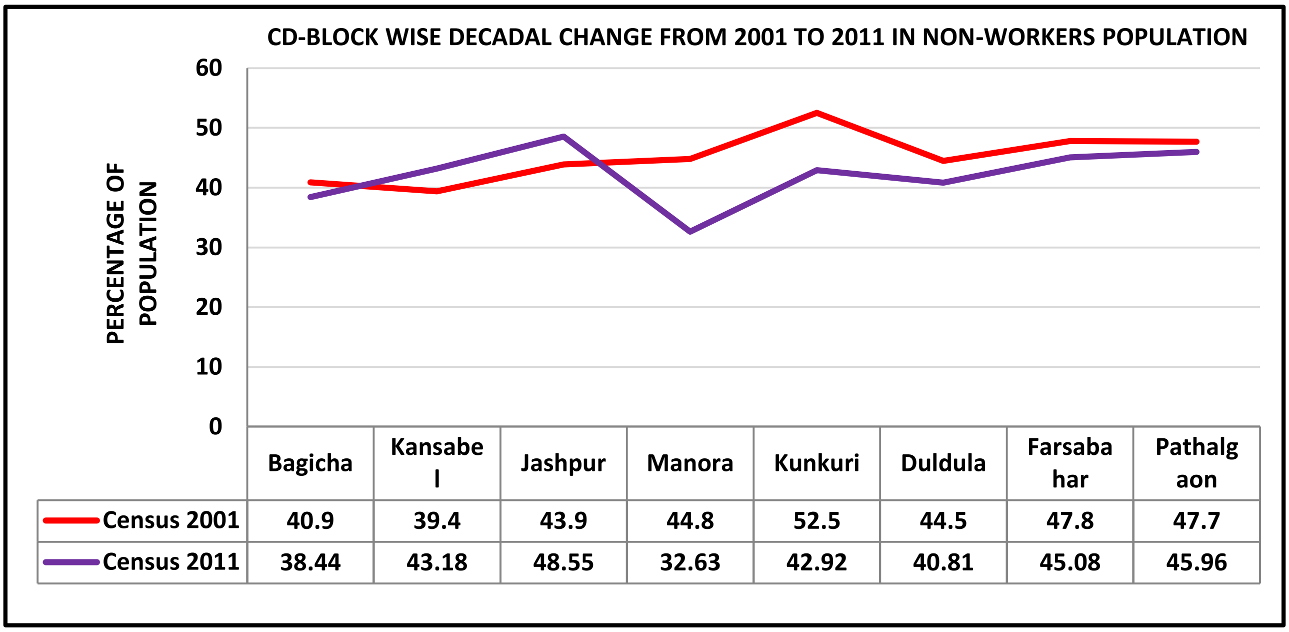

FIGURE 6: CD-Block wise decadal change from 2001 to 2011 in non-workers population.

3.4.3 Decadal Change in Cultivators:

The decadal change of cultivators was - 17.55 % from 2001 to 2011 in the study area which indicate the decline trend of cultivator's population in percentage due to a combination of factors including a shift towards agricultural labor, a decrease in the viability of farming and a movement of people towards non-agricultural sectors which is shown in the table 2 & fig. 3. Under the categories of cultivators, negative decadal change has been found in all CD-Block from 2001 to 2011 in the study area was primarily due to a shift towards non-farm activities and agricultural laborers. This shift is often driven by factors such as lower income from agriculture, migration to urban areas, and the search for better livelihood opportunities, which is shown in the table 5 & fig. 7.

TABLE 5
CD-BLOCK WISE DISTRIBUTION OF CULTIVATORS & DECADAL CHANGE FROM 2001 TO 2011

Name of CD-Blocks	Category of Workers: Cultivators					
	Numbers			Percentage (%)		
	Census 2001	Census 2011	Decadal Change 2001-11	Census 2001	Census 2011	Decadal Change 2001-11
Bagicha	57588	42989	- 14599	65.80	40.67	- 25.13
Kansabel	27240	24371	- 2869	65.00	55.89	- 9.11
Jashpur	25166	24587	- 579	73.50	49.59	- 23.91
Manora	23005	30247	+ 7242	77.60	73.97	- 3.63
Kunkuri	21285	24488	+ 3203	54.40	45.02	- 9.38
Duldula	16232	11459	- 4773	64.30	38.08	- 26.22
Farsabahar	29723	20161	- 9562	57.90	33.84	- 24.06
Pathalgaon	48433	48564	+ 131	61.40	46.92	- 14.48
Jashpur District	**248672**	**226866**	**- 21806**	**64.10**	**46.55**	**- 17.55**

Source: District Census Handbook - 2001 & 2011, Jashpur district (C.G.).

3.4.4 Decadal Change in Agricultural Labourers:

The decadal change of agricultural labourers was + 14.94 % from 2001 to 2011 in the study area which witnessed a positive growth in percentage due to a shift in the tribal population from being cultivators to agricultural labourers. This shift saw a decline in the proportion of cultivators and a corresponding increase in agricultural labourers, which is shown in the table 2 & fig. 3. Positive decadal change has been found in the agricultural labourers among all CD-Block from 2001 to 2011 due to a shift in the tribal population's livelihood, with a notable decline in cultivators and corresponding rises in agricultural labourers as well as a significant number are transitioning from being cultivators to agricultural labourers, which is shown in the table 6 & fig. 7.

TABLE 6
CD-BLOCK WISE DISTRIBUTION OF AGRICULTURAL LABOURERS & DECADAL CHANGE FROM 2001 TO 2011

Name of CD-Blocks	Category of Workers: Agricultural Labourers					
	Numbers			Percentage (%)		
	Census 2001	Census 2011	Decadal Change 2001-11	Census 2001	Census 2011	Decadal Change 2001-11
Bagicha	20734	52040	+ 31306	23.70	49.23	+ 25.53
Kansabel	10829	15065	+ 4236	25.80	34.55	+ 8.75
Jashpur	4416	10185	+ 5769	12.90	20.54	+ 7.64
Manora	3927	7771	+ 3844	13.30	19.00	+ 5.70
Kunkuri	11160	21162	+ 10002	28.50	38.90	+ 10.40
Duldula	6841	14593	+ 7752	27.10	48.49	+ 21.39
Farsabahar	16877	33198	+ 16321	32.90	55.72	+ 22.82
Pathalgaon	24684	43544	+ 18860	31.30	42.07	+ 10.77
Jashpur District	**99468**	**197558**	**+ 98090**	**25.60**	**40.54**	**+ 14.94**

Source: District Census Handbook - 2001 & 2011, Jashpur district (C.G.).

3.4.5 Decadal Change in Household Industry Workers:

The decadal change of household industry workers was - 1.15 % from 2001 to 2011 in Jashpur district which indicate the negative growth in percentage. The decline in household industry workers in the study area from 2001 to 2011 can be attributed to a combination of various factors such as the increasing influence of larger industries, migration, and potentially changing economic priorities within the district as well as these factors likely led to a shift away from traditional household-based work, which is shown in the table 2 & fig. 3. A negative decadal change has been found in the household industry workers among all CD-Block from 2001 to 2011 was likely due to a combination of factors including the modernization and mechanization of industries, leading to a shift away from traditional household-based work, which is shown in the table 7 & fig. 7.

TABLE 7
CD-BLOCK WISE DISTRIBUTION OF HOUSEHOLD INDUSTRY WORKERS & DECADAL CHANGE FROM 2001 TO 2011

Name of CD-Blocks	Category of Workers: Household Industry Workers					
	Numbers			Percentage (%)		
	Census 2001	Census 2011	Decadal Change 2001-11	Census 2001	Census 2011	Decadal Change 2001-11
Bagicha	2472	1534	- 938	2.80	1.45	- 1.35
Kansabel	1135	796	- 339	2.70	1.83	- 0.87
Jashpur	1189	1033	- 156	3.50	2.08	- 1.42
Manora	641	347	- 294	2.20	0.85	- 1.35
Kunkuri	1422	739	- 683	3.60	1.36	- 2.24
Duldula	633	608	- 25	2.50	2.02	- 0.48
Farsabahar	1414	1291	- 123	2.80	2.17	- 0.63
Pathalgaon	1482	1205	- 277	1.90	1.16	- 0.74
Jashpur District	**10388**	**7553**	**- 2835**	**2.70**	**1.55**	**- 1.15**

Source: District Census Handbook - 2001 & 2011, Jashpur district (C.G.).

3.4.6 Decadal Change in Other workers:

The decadal change of other workers population was + 3.76 % from 2001 to 2011 in Jashpur district which indicate the positive growth of other workers in percentage. In the study area the increase in the other workers population from 2001 to 2011 is primarily attributed to a shift in livelihood patterns within the tribal population, particularly a transition from cultivation to other forms of labor. This shift is part of a broader trend of migration from agriculture to informal labor markets as well as the overall population of Jashpur district increased during this period, which is shown in the table 2 & fig. 3. Basically a positive decadal change has been found in other workers among the all CD-Block from 2001 to 2011 due to various causes including a shift from cultivation to other forms of labor, migration into the district, and increased participation in the informal sector, which is shown in the table 8 & fig. 7.

TABLE 8
CD-BLOCK WISE DISTRIBUTION OF OTHER WORKERS & DECADAL CHANGE FROM 2001 TO 2011

Name of CD-Blocks	Category of Workers: Other Workers					
	Numbers			Percentage (%)		
	Census 2001	Census 2011	Decadal Change 2001-11	Census 2001	Census 2011	Decadal Change 2001-11
Bagicha	6661	9145	+ 2484	7.60	8.65	+ 1.05
Kansabel	2708	3370	+ 662	6.50	7.73	+ 1.23
Jashpur	3449	13772	+ 10323	10.10	27.78	+ 17.68
Manora	2063	2526	+ 463	7.00	6.18	- 0.82
Kunkuri	5291	8007	+ 2716	13.50	14.72	+ 1.22
Duldula	1542	3433	+ 1891	6.10	11.41	+ 5.31
Farsabahar	3343	4932	+ 1589	6.50	8.28	+ 1.78
Pathalgaon	4310	10198	+ 5888	5.50	9.85	+ 4.35
Jashpur District	**29367**	**55383**	**+ 26016**	**7.60**	**11.36**	**+ 3.76**

Source: District Census Handbook - 2001 & 2011, Jashpur district (C.G.).

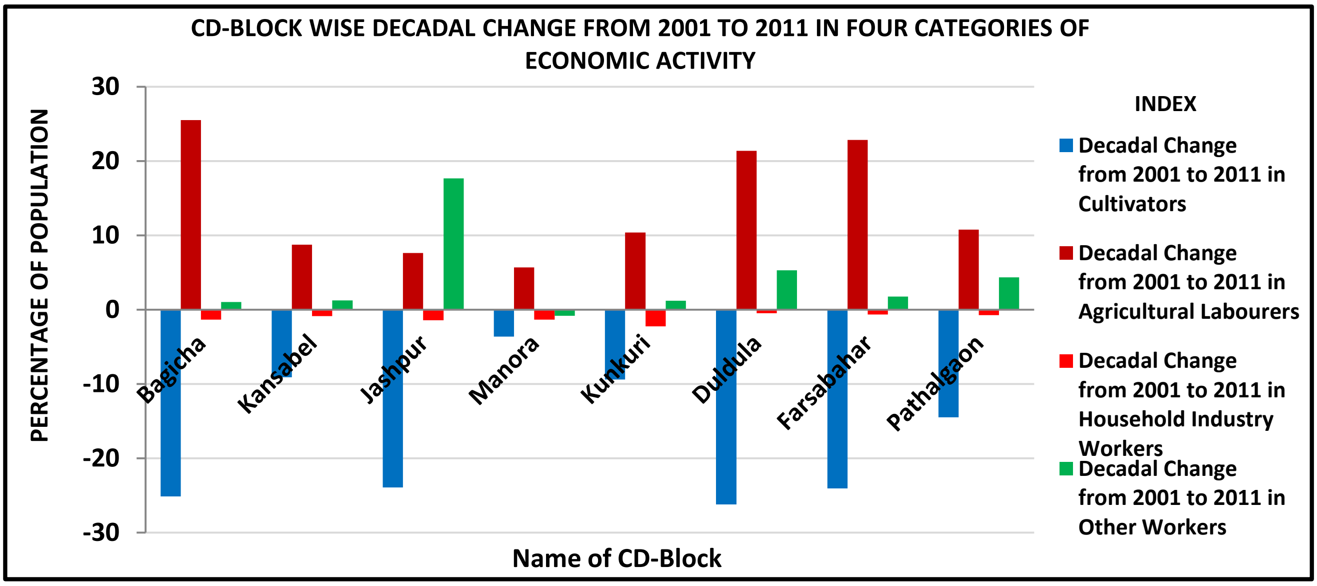

FIGURE 7: CD-Block wise decadal change from 2001 to 2011 in four categories of economic activity.

IV. CONCLUSION

To conclude, the occupational structure of Jashpur district is predominantly agriculture based, with a major portion of the population engaged in agriculture and allied activities. The occupational structure in Jashpur district is rapidly changing, as most people are moving away from traditional agricultural practices towards a more diversified economy. This change is marked by a decline in the proportion of the workforce engaged in agriculture and a corresponding increase in the proportion of those employed in secondary and tertiary sectors such as manufacturing and services. Not only this, there has been a significant decline in the proportion of main workers and an increase in marginal workers, along with a reduction in the overall working population. This is partly due to a decline in agricultural activities and an increase in rural-urban migration in search of employment. By carefully planning and managing the occupational structure, the study area can ensure a more prosperous, equitable and sustainable future for their citizens.

DISCLAIMER (ARTIFICIAL INTELLIGENCE):

Author (s) hereby declare that NO generative AI technologies such as Large Language Models (Chat GPT, COPILOT, etc.) and text-to-image generators have been used during writing or editing of this manuscript.

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CONFLICT OF INTEREST:

There is no conflict of interest in this present research paper. This research work is not a part of any other studies and it is our original work.

REFERENCES

[1] Chandana, R. C. (2010). *Geography of Population: Concepts, Determinants and Patterns*. New Delhi: Kalyani Publisher, pp. 308-331.
[2] Census of India: 2001 & 2011, District Census Handbook of Jashpur District, Village and Town Wise Primary Census Abstract, Directorate of Census Operations, Chhattisgarh State.
[3] Kumari, Shivangi and Kumar, Aniruddh (2024). Changing Pattern of Occupational Structure in Katihar District: A Geographical Analysis. *International Journal of Creative Research Thoughts (IJCRT)*, 12(2), 28-36, ISSN: 2320-2882.
[4] Karthikesan, K., Emayavaramban, V., Kanndasan, K. and Vinoothakanna, S. (2018). A Geographical Analysis of Occupational Structure in Nagapattinam District, Tamil Nadu. *Research Review International Journal of Multidisciplinary*, 3(10), 565-571.
[5] Khadke, P.A., Kharat, R.U. and Kamble, K.R. (2019). Changing Occupational Structure in Aurangabad City. *International Journal of Research in Engineering IT and Social Science*, 9(3), 25- 32.
[6] Kumar, P., Kumar, N. and Singh, J. (2016). Changes in Occupational Structure of Rural Population: A Study of Jaunpur District (Uttar Pradesh). *Uttar Bharat Bhoogol Patrika*, 46(2), 17-25.
[7] Reddy, A.A. and Kumar, P. (2009). Occupational Structure of Workers in Rural Andhra Pradesh. *Journal of Indian School of Political Economy*, 18(1&2), 77-91.
[8] Singh, R.P. (2015). Spatial Pattern of Occupational Structure in Haryana. *Paripex - Indian Journal of Research*, 4(6), 418-420.
[9] Rai, G. and Kumari, B. (2012). Occupational Structure of Chiraigaon Development Block, Varanasi District. *National Geographical Journal of India*, 58, 34 - 40.
[10] Rina and Godara, Rohtas (2020). An Analysis of Occupational Structure: A Case Study of Panchkula District. *Shodh Sanchar Bulletin*, 10(39), 123-130, ISSN: 2229-3620.
[11] Patidar, H. and Singh, M.B. (2010). Occupation Structure of Tribal Population in South East Rajsthan: A Geographical Analysis. *National Geographical Journal of India*, 56(1), 31-42.
[12] Verma, Kamlesh and Rai, V.K. (2020). Changes in Occupational Structure of Population in Ballia district: A Geographical study. *NGJI - An International Peer-Reviewed Journal*, 66(2), 136-149, ISSN: 0027- 9374/2020/1736

Assessment of Irrigation Water Quality Parameters of Water Resources used to Irrigate Agricultural Fields of Alemdar Neighborhood of Konya Çumra District

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***Abstract*—** *This study was conducted to assess water quality parameters of water samples taken from irrigation wells used to irrigate agricultural fields of Alemdar Neighborhood of Konya-Çumra District. Water samples were taken in June, July, August, September and October. The pH values of irrigation water samples varied between 7.11 – 8.12, EC values varied between 580 - 1150 µmhos/cm. Irrigation water salinity classes were identified as* C_2S_1 *(moderately saline - low alkaline) and* C_3S_1 *(highly saline - low alkaline). Boron concentration of all samples was below the threshold boron level of 0.67 ppm.*

***Keywords*— Irrigation, irrigation water quality, saline irrigation water, boron.**

I. INTRODUCTION

Water quality and soil salinity are among the most important issues to consider in sustainable agricultural production. In recent years, water resources have been under great pressure due to both the negative effects of climate change and increasing water demands. Groundwater resources, which play a crucial role in water resources, are deteriorating both in quality and quantity over time. Such a case is particularly evident in basins such as the Konya Closed Basin. Irrigation carries dissolved salts into the soil. Depending on the characteristics of the water source, salinity and alkalinity problems may arise over time in irrigated areas, and if no measures are taken, these problems can reach levels that restrict or eliminate agricultural production **[1].**

[2] took monthly water samples from the surface and different depths in three sampling points of Boztepe Recai Kutan Reservoir Lake in Malatya province to determine the water quality of the reservoir lake and analyzed temperature, pH, dissolved oxygen, and electrical conductivity parameters and indicated water quality class of the reservoir lake as Class II (good quality water).

[3] indicated that in modern irrigation systems, the quality of irrigation water is as important as the amount of irrigation water, irrigation time, and irrigation method. When sufficient and good-quality water is not available, water that is unsuitable for irrigation is used. This increases the salinity problem in the soil. Therefore, in order to evaluate the water quality in the ponds used for irrigation in Hakkari province, water samples were taken from 10 irrigation ponds in June, July, August, and September. The water samples were analyzed for electrical conductivity (EC), pH, anions, and cations (Ca^{2+}, Mg^{2+}, K^+, Na^+, SO_4^{2-}, NO_3^{2-}, CO_3^{2-}, HCO_3^-, and Cl^-). Additionally, using the obtained data, the Sodium Adsorption Ratio (SAR), Residual Sodium Carbonate (RSC), and Sodium Percentage (% Na) values were calculated. At the end of the study, it was determined that the pH, EC, SAR, RSC, and % Na values of the irrigation pond waters did not exceed the threshold values, but the Mg^{+2} and K^+ values of the pond water in the Kanatlı area of Akçalı Village and the K^+ value of the pond water in the Şişer area of Kırıkdağ Village exceeded the threshold values.

[4] conducted a study to evaluate the quality of water samples taken from irrigation wells used to irrigate agricultural fields in the Hatunsaray neighborhood of Meram district, Konya province. Researchers took water samples from the wells used for irrigation and also collected soil samples from the agricultural fields irrigated by these wells at depths of 0-30, 30-60, and 60-90 cm. It was determined that most of the soils in the region were loamy (L) and clay-loam (CL) in texture, with soil pH values ranging from 7.94 to 9.10 and EC values ranging from 242 to 857 µmhos/cm. EC values of the water samples ranged from 198 to 772 µmhos/cm, pH values ranged from 6.91 to 8.38, and water salinity class was identified as C_2S_1 (moderately saline - low alkaline). It was recommended that drainage systems should be constructed to prevent salinity problems in agricultural areas and the periodic maintenance and repair of existing drainage channels should be carried out and the necessary cultural measures should be taken to prevent potential salinity problems in the coming years.

[5] conducted a study in the Biga Plain of Çanakkale province to analyze water samples taken from 20 wells for electrical conductivity (EC), pH, potassium (K), calcium (Ca), magnesium (Mg), Sodium (Na), Carbonate (CO_3), Bicarbonate (HCO_3), Chloride (Cl), Sulfate (SO_4), Nitrate (NO_3), and Boron (B) parameters. When classified according to the Water Pollution Control Regulation (SKKY) Classification System and considering the salinity parameter, 11 of the 20 wells were classified as second class, while the others were classified as first class. The study found that, apart from nitrate pollution in groundwater, no significant problems had yet emerged in the study area.

[6] conducted a study in the Isparta Plain to examine the quality of irrigation water samples taken from 21 groundwater wells and found that the water quality in some of the wells was classified as C_3S_1 (highly saline - low alkaline), while the water quality in other wells was classified as C_2S_1 (moderately saline - low alkaline).

[7] conducted a study to determine the irrigation water quality of water sources used in some agricultural lands in the Mersin-Mezitli district and the salinity level of agricultural lands irrigated with these waters. It was determined the pH values of irrigation water samples taken in July, August, September, and October ranged from 7.05 to 8.26, and the EC values ranged from 292 to 1103 µmhos/cm, the water samples were classified as C_2S_1 and C_3S_1 irrigation water according to the US Salinity Laboratory Classification System, falling into the medium and high salinity irrigation water categories, while boron levels were found to be below the optimal limit of 0.67 ppm in all samples. Additionally, the soils in the study area were found to be clay, loamy, and clay-loam in texture with pH values ranging from 7.38 to 7.95 and EC values ranging from 1985 to 3180 µmhos/cm in August. The soil salinity was found to be below the soil salinity threshold value of 4000 µmhos/cm. It was determined that there were no significant differences in quality or quantity in the water samples throughout the irrigation period (July-October), and that the soil samples did not pose any problems in terms of salinity and boron under the current conditions.

[8] conducted a study to determine the impact of domestic and industrial wastes on the Nilüfer River. Researchers collected wastewater samples from the discharge points of five wastewater treatment plants discharging into the Nilüfer River and from the streams into which these plants discharge during four different periods between August 2013 – May 2014. The results of the study showed that the water quality parameters of the Nilüfer River and some of the wastewater treatment plants discharging into the Nilüfer River varied depending on the period. Based on the classification made considering EC and SAR, the water samples were categorized into C_2S_1 - C_4S_4 classes, and that the water parameters of the Nilüfer River before and after discharge showed that the wastewater discharged from the treatment plants had a negative impact on the Nilüfer River, particularly in terms of pH, EC, ammonium, phosphorus, sulfate, boron, and chlorine values.

[9] conducted a study in the Sultanhisar district of Aydın Province and found that the quality of water used for irrigation varied between C_2S_1 and C_3S_1 classes over time, that the canal water used affected fruit quality, and that the boron content of these waters was higher than that of the control group plants.

[10] selected a total of 17 sampling sites along the Awash River and its tributaries and conducted sampling four times a year in different seasons to assess the water quality of the Awash River and its tributaries. Researchers assessed the overall water quality and suitability for irrigation using numerous water quality parameters such as pH, EC, SAR, RSC, Na^+, K^+, Ca^{++} , Mg^{++}, CO_3^{2-}, HCO_3^-, and Cl^-. It was determined that all quality parameters in Lake Beseka exceeded the maximum permissible limits for irrigation, the physicochemical characteristics of the Awash River showed variations in different water quality parameters across different sites. Only the pH and SAR of Beseka Lake and Meteka hot spring water exceeded the permitted limit, and the EC values in Mojo, Wonji, Beseka, Melkasedi, Werer, Ambash, Meteka, and Meteka hot springs showed medium-high salinity values, while the RSC was very high. It was recommended that wastewater treatment plants should be constructed for industries to improve water quality.

Soil salinization and alkalinity are common processes that characterize arid areas in particular. These processes can be attributed to natural conditions or anthropogenic activities. Natural factors include climate, lithology, topography, and pedology, while human-induced factors are mostly related to agricultural land use and, in particular, irrigation. Over time, the extent of saline, alkaline, and saline-alkaline agricultural areas has increased, leading to accelerated land degradation and desertification, reduced agricultural productivity, and ultimately jeopardizing environmental and food security. Mapping and monitoring saline soils is an important management tool aimed at determining the extent and severity of salinization processes. Recent advances in remote sensing methods have increased the effectiveness of mapping and monitoring processes of saline soils. Knowledge on the prevention, reduction, and improvement of soil salinity and alkalinity has increased significantly over time **[11].**

II. MATERIAL AND METHODS

Water samples were taken from 20 irrigation wells used to irrigate agricultural fields of Alemdar Neighborhood of Çumra District of Konya province in June, July, August, September and October.

Konya Province is located in the southern part of the Central Anatolia Region. While most of its land consists of high plateaus, the southern and southwestern parts of Konya Province are in the Mediterranean Region. Geographically, Konya is located between 36°41' and 39°16' north latitudes and 31°14' and 34°26' east longitudes **[12].** It has an area of 38,257 km² (excluding lakes). It is the largest province of Turkey in terms of area. The average elevation is 1,016 m **[13].**

In the higher elevations of Konya Province, where a continental climate prevails, winters are cold and rainy, while summers are hot during the day and cool at night. The temperature difference between night and day is significant, and precipitation is quite low **[14].** Convective rainfall occurs in the spring, and most of annual precipitations fall during this season. The annual average rainfall in the region is 329 mm. Due to the varying topography of Konya Province, the average annual rainfall amounts also differ **[15].** While the monthly average temperature values in the region range from -0.2 °C to 23.5 °C, a steady increase in temperature has been observed when long-term temperature changes are examined. Evaporation values reach their highest levels during the summer months. The evaporation value in July is 280 mm, with an annual total of 952 mm **[12].**

The district of Çumra, located 43 km from the center of Konya, is situated on the Konya-Karaman highway and railway route. The district is bordered by Karatay to the north, Karapınar to the east, Akören and Meram to the west, Bozkır and Güneysınır districts to the southwest, and province of Karaman to the southeast. It is generally located between 37^0-38^0 east longitudes and 33^0-34^0 north latitudes. The district has an area of 2,330 km², with 90% of the land being flat and 10% consisting of mountainous and forested areas. The district's elevation above sea level is 1,013 meters, and the highest point in the region is Karadağ Mountain, which separates Çumra from Karaman at an elevation of 2,288 meters. The Çarşamba River, Apa Dam Lake, and Hotamış Lake, which will be replenished with water through the Blue Tunnel Project, are the district's most important water resources **[16].**

The climate in Çumra and its surroundings is cold and snowy in winter and hot and dry in summer. Autumn and spring are the rainy seasons. However, in recent years, parallel to on-going climate change in Turkiye, snowfall in winter has decreased significantly. The Çumra Meteorological Station was established in 1927 and is the first meteorological station established in the Konya region. The lowest temperature in Çumra was recorded at -26.8 °C in 1964, and the highest temperature was 39.9 °C in 2000. The highest rainfall in the district was 50.1 kg/m² in 2003, and the highest snowfall was 52 cm in 1976. The average temperature of the district is 11.27 °C. The soil structure of Çumra is diverse. The alluvial soils that cover a large part of the plain are quite fertile and rich in minerals. However, these soils have problems such as salinity and wind erosion. The plain has a flat topography. Fifty percent of the land is flat, 17% is slightly sloped, 14% is moderately sloped, 13% is steep, and 6% is highly steep.

Approximately 114,000 hectares of land are used for agriculture in the Çumra Plain. Approximately 80,000 hectares of this area are used for irrigated agriculture, while the remaining area is used for dry farming. The most commonly grown crops in Çumra are wheat, barley, sugar beet, dry beans, and chickpeas.

The research area, Alemdar neighborhood, is located 9 km from Çumra and 51 km from Konya. The location of the research area is shown in Figure 1.

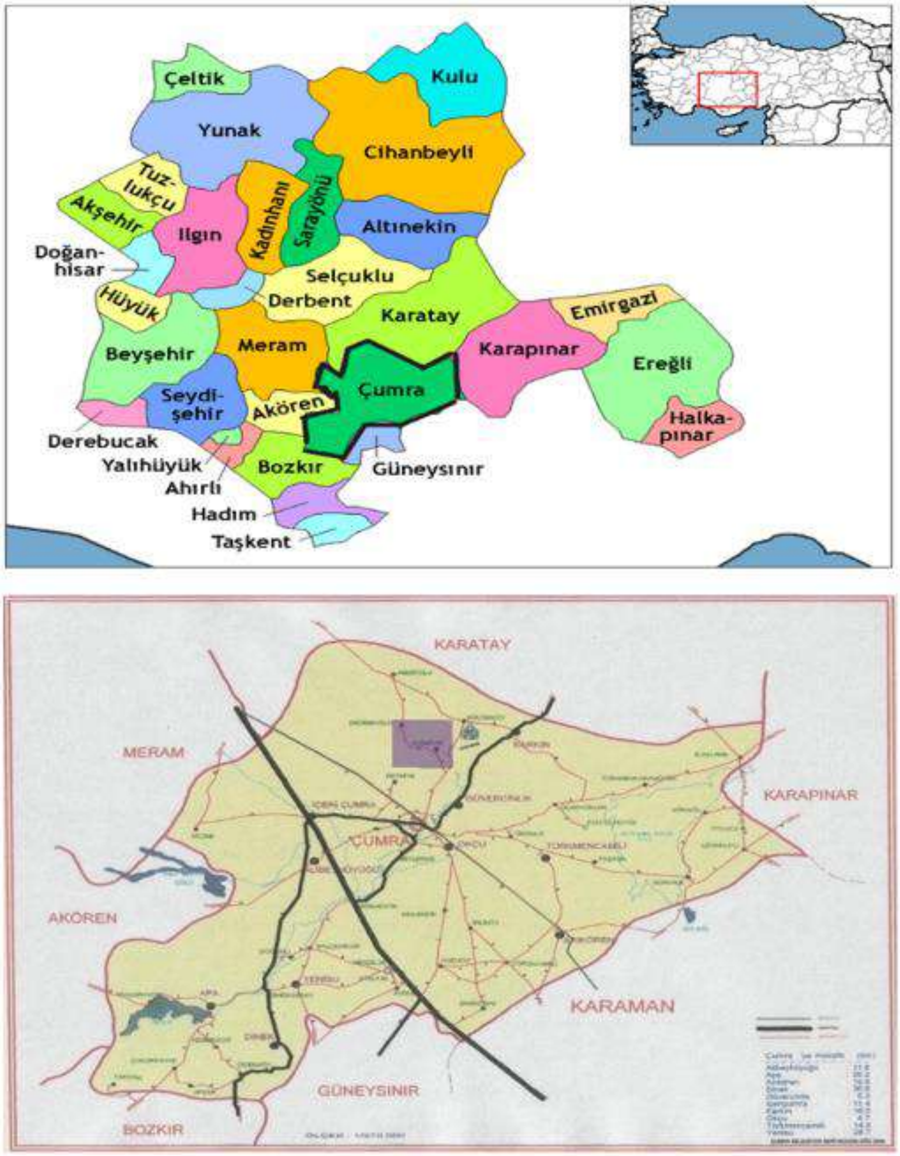

FIGURE 1: Location of the research site

Monthly water samples were taken regularly for five months during the irrigation period (June-October) from 20 irrigation water wells in irrigated agricultural fields of Alemdar Neighborhood of Çumra District. The pH and EC readings were taken, and in August, analyses were conducted to determine soluble cations (Ca, Mg, Na, K) and anions (CO_3, HCO_3, Cl, and SO_4) in the water, as well as boron content. Analysis results were used to calculate %Na, SAR, RSC, and irrigation water class.

III. RESULT AND DISCUSSION

Water samples were taken from the water resources (wells) used for irrigation of the research area once a month for five months (June, July, August, September, and October) during the irrigation season.

The pH and EC values of the irrigation water samples taken in June, July, August, September, and October, are presented in Table 1. In June, the pH values of the irrigation water samples ranged from 7.15 to 8.00, and the EC values ranged from 580 to 1100 µmhos/cm. In July, the pH values of the irrigation water ranged from 7.35 to 8.05, and the EC values ranged from 690 to 1095 µmhos/cm. In August; the pH values of irrigation water samples were between 7.48 - 8.12, and the EC values were between 810 - 1150 µmhos/cm. In September; the pH values of irrigation water were between 7.33 - 8.09, and the EC values were between 775 - 1040 µmhos/cm. In October, the pH values of the irrigation water samples were between 7.11 – 7.91, and the EC values were between 751 - 935 µmhos/cm. The EC values of irrigation water samples taken from the region in June, July, August, September, October and sample numbers are presented in Figures 2, 3, 4, 5, and 6.

In June, the highest salinity values were seen in samples 16 and 17, while samples 4, 6, 7, 9, 14, 15, 16, 17, 18, 19, and 20 had salinity levels above the threshold salinity level of 750 µmhos/cm. The remaining samples had salinity levels below the threshold salinity level of 750 µmhos/cm, making them more suitable for use in irrigating fields. In July, the highest salinity values were seen in samples 15 and 17. All other samples, except for samples 1, 2, 5, 10, and 11, exceeded the threshold value (750 µmhos/cm). It can be stated that these samples are not suitable for irrigation purposes in terms of salinity. In August, the highest salinity values were seen in samples 7, 14, 15, 16, and 17. All samples exceeded the threshold value (750 µmhos/cm), and it can be said that they are not suitable for use in irrigating fields in terms of salinity. In September, the highest salinity values were seen in samples 7 and 14, and all samples exceeded the threshold salinity level of 750 µmhos/cm, making them unsuitable for use in irrigating fields in terms of salinity. In October, the highest salinity values were seen in samples 7, 14, 15, and 17, and all samples exceeded the threshold value of 750 µmhos/cm, making them unsuitable for irrigation purposes.

The chemical analysis results of irrigation water samples for August are given in Table 2. The pH values of the irrigation waters ranged from 7.48 to 8.12, the EC values ranged from 810 to 1150 µmhos/cm, and the boron values were below the optimal limit of 0.67 ppm in all samples. In terms of soluble anions and cations in the water, Ca was the dominant cation and SO_4 was the dominant anions. Sodium Adsorption Ratios (SAR) ranged from 0.51 to 1.29, while %Na values ranged from 10.22 to 23.91. Water samples from August were classified as C_3S_1 irrigation water according to the US Salinity Laboratory Classification System.

In terms of boron values of the irrigation water samples in Table 2, all samples were below the safe boron value (0.7 ppm), and it can be stated that there will be no boron-related issues in August irrigation.

TABLE 1
THE pH AND EC ANALYSIS RESULTS OF IRRIGATION WATER SAMPLES TAKEN IN JUNE, JULY, AUGUST, SEPTEMBER AND OCTOBER

Sample No	June		July		August		September		October	
	pH	EC x 10^6 µmhos/cm 25 ºC	pH	EC x 10^6 µmhos/cm 25 ºC	pH	EC x 10^6 µmhos/cm 25 ºC	pH	EC x 10^6 µmhos/cm 25 ºC	pH	EC x 10^6 µmhos/cm 25 ºC
1	7,79	625	7,51	740	7,80	810	8,09	775	7,75	751
2	7,45	580	7,66	735	8,02	850	7,78	805	7,60	795
3	7,85	750	7,90	800	8,05	860	7,80	800	7,80	768
4	7,61	790	7,84	855	8,09	901	7,90	842	7,63	801
5	7,50	695	7,60	750	7,98	849	7,76	807	7,55	803
6	7,29	951	7,35	1010	7,52	1045	7,45	976	7,40	900
7	7,38	970	7,42	1080	7,48	1100	7,55	1000	7,69	915
8	7,65	695	7,90	840	7,95	960	7,71	895	7,78	826
9	7,66	851	7,85	1020	7,90	1050	7,75	953	7,91	855
10	7,50	690	7,65	690	7,65	841	7,50	810	7,60	765
11	7,77	645	7,94	750	7,99	910	7,63	860	7,50	772
12	8,00	750	8,05	895	8,02	1010	7,70	920	7,45	810
13	7,95	655	8,00	810	8,12	870	7,90	840	7,74	765
14	7,30	1010	7,54	1070	7,65	1120	7,50	1040	7,11	935
15	7,15	1070	7,35	1095	7,48	1150	7,43	995	7,25	918
16	7,41	1100	7,66	1080	7,91	1130	7,74	970	7,63	885
17	7,29	1090	7,53	1095	7,55	1110	7,33	965	7,56	910
18	7,35	1075	7,43	1045	7,49	1075	7,37	910	7,69	880
19	7,77	980	7,95	1005	7,91	1025	7,65	905	7,65	795
20	7,51	1000	7,78	995	7,90	1000	7,80	900	7,85	790

TABLE 2
CHEMICAL ANALYSIS RESULTS OF THE IRRIGATION WATER SAMPLES TAKEN IN AUGUST

Sample No	pH	ECx10^6 µmos/cm 25 °C	Water-Soluble										RSC	SAR	%Na	Irrigation Water Class	Boron (mg/L)
			Cations (me/l)					Anions (me/l)									
			Na^+	K^+	Ca^{+2}	Mg^{+2}	Total	CO_3^{-2}	HCO_3^-	Cl^-	SO_4^{-2}	Total					
1	7,80	810	1,65	0,22	3,88	2,45	8,20	0,00	1,71	2,95	3,59	8,25	-	0,93	20,12	C_3S_1	<0,67
2	8,02	850	1,59	0,28	4,21	2,69	8,70	0,00	1,40	2,89	4,36	8,65	-	0,85	18,28	C_3S_1	<0,67
3	8,05	860	1,47	0,33	3,94	2,91	8,65	0,00	1,61	3,21	3,88	8,70	-	0,79	16,99	C_3S_1	<0,67
4	8,09	901	1,21	0,18	4,84	2,77	9,00	0,00	2,01	3,45	3,64	9,10	-	0,62	13,44	C_3S_1	<0,67
5	7,98	849	1,14	0,16	4,65	2,80	8,75	0,00	1,95	3,54	3,11	8,60	-	0,59	13,03	C_3S_1	<0,67
6	7,52	1045	2,10	0,35	4,25	4,00	10,70	0,00	2,01	3,88	4,66	10,55	-	1,03	19,63	C_3S_1	<0,67
7	7,48	1100	1,15	0,95	6,21	2,94	11,25	0,00	1,60	3,40	6,00	11,00	-	0,54	10,22	C_3S_1	<0,67
8	7,95	960	1,08	0,08	4,44	4,25	9,85	0,00	0,95	4,06	4,89	9,90	-	0,52	10,96	C_3S_1	<0,67
9	7,90	1050	2,57	0,15	4,29	3,74	10,75	0,00	0,64	5,25	4,91	10,80	-	1,29	23,91	C_3S_1	<0,67
10	7,65	841	1,41	0,08	3,88	3,13	8,50	0,00	0,58	3,41	3,39	8,60	-	0,75	16,59	C_3S_1	<0,67
11	7,99	910	1,20	0,12	4,21	3,82	9,35	0,00	0,75	3,94	4,76	9,45	-	0,60	12,83	C_3S_1	<0,67
12	8,02	1010	1,35	0,41	5,62	3,02	10,40	0,00	1,35	4,22	5,08	10,65	-	0,65	12,98	C_3S_1	<0,67
13	8,12	870	1,00	0,23	4,63	2,99	8,85	0,00	1,12	2,98	4,55	8,65	-	0,51	11,30	C_3S_1	<0,67
14	7,65	1120	1,45	0,30	6,59	3,21	11,55	0,00	1,95	4,89	4,86	11,70	-	0,66	12,55	C_3S_1	<0,67
15	7,48	1150	1,65	0,42	6,99	2,74	11,80	0,00	1,52	5,09	5,34	11,95	-	0,75	13,98	C_3S_1	<0,67
16	7,91	1130	1,74	0,65	6,52	2,74	11,65	0,00	1,48	5,51	4,51	11,50	-	0,81	14,93	C_3S_1	<0,67
17	7,55	1110	2,34	0,41	6,23	2,52	11,50	0,00	1,33	3,56	6,71	11,60	-	1,12	20,35	C_3S_1	<0,67
18	7,49	1075	2,42	0,36	4,84	3,38	11,00	0,00	1,30	3,25	6,35	10,90	-	1,19	22,00	C_3S_1	<0,67
19	7,91	1025	2,00	0,18	4,78	3,59	10,55	0,00	1,05	3,80	5,75	10,60	-	0,98	18,96	C_3S_1	<0,67
20	7,90	1000	1,78	0,32	4,62	3,48	10,20	0,00	1,00	3,26	5,84	10,10	-	0,89	17,45	C_3S_1	<0,67

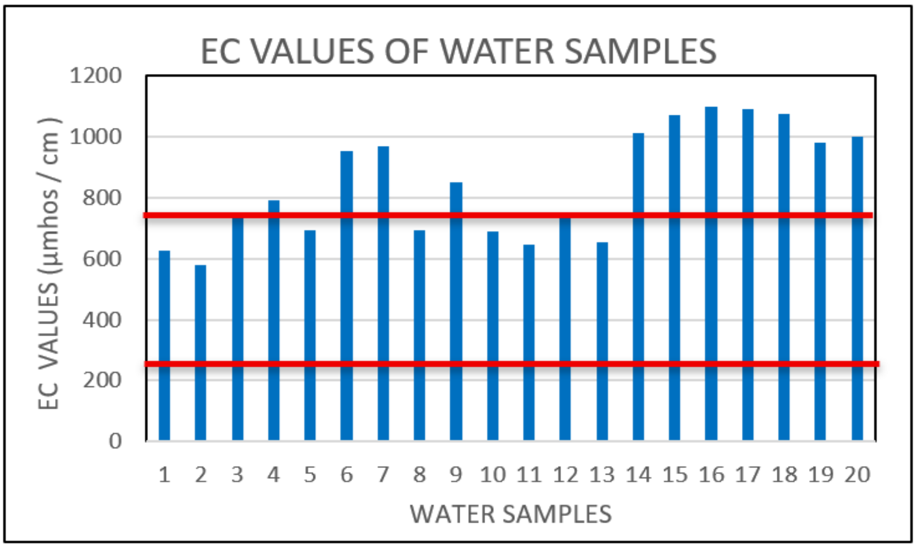

FIGURE 2: EC values of irrigation water samples taken in June

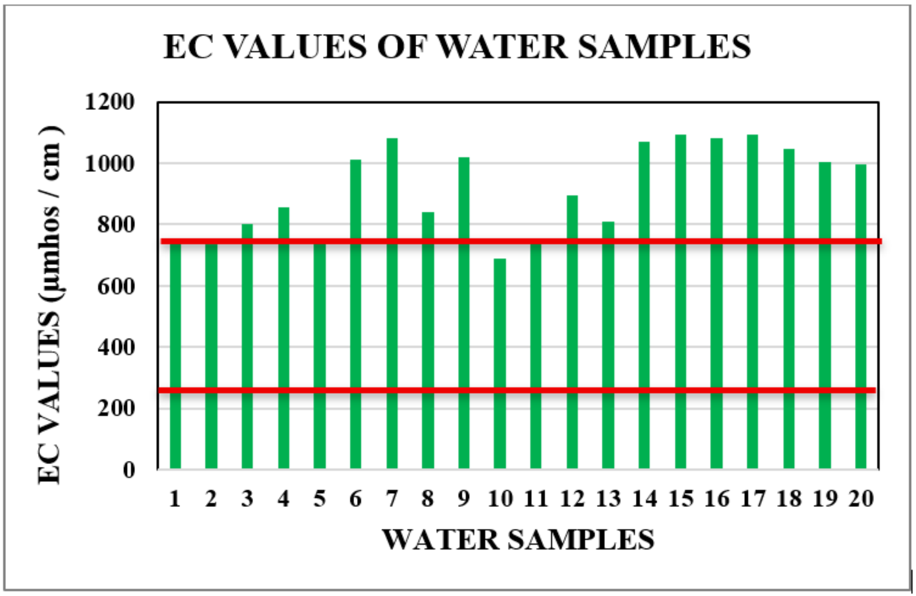

FIGURE 3: EC values of irrigation water samples taken in July

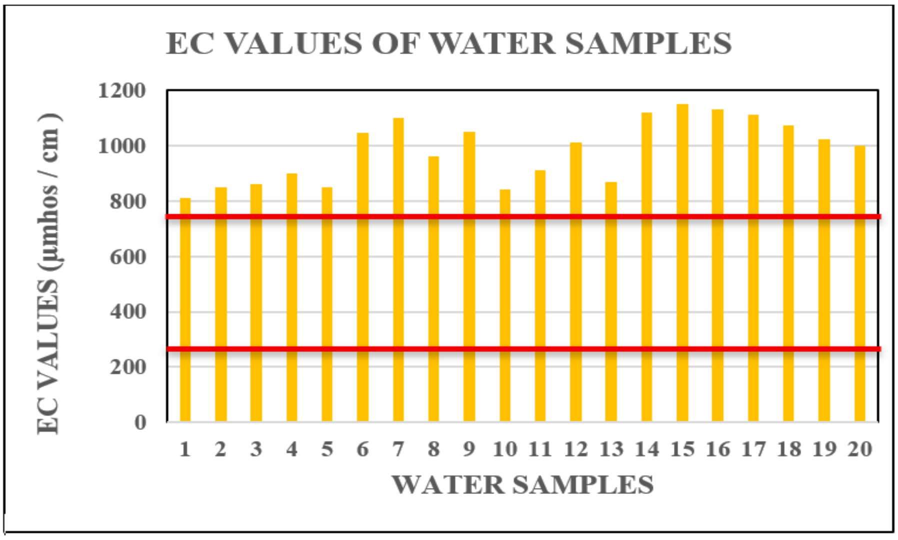

FIGURE 4: EC values of irrigation water samples taken in August

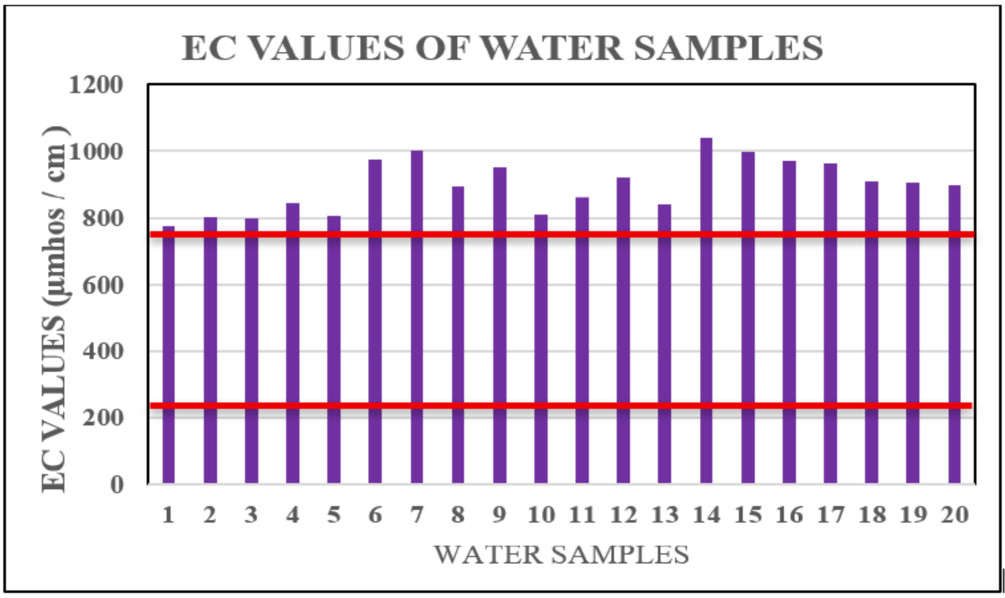

FIGURE 5: EC values of irrigation water samples taken in September

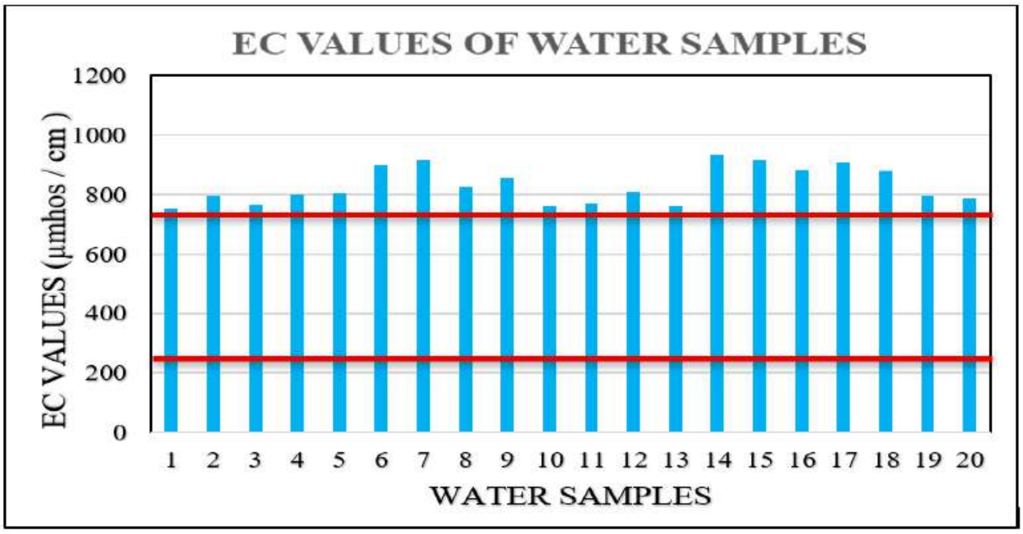

FIGURE 6: EC values of irrigation water samples taken in October

IV. CONCLUSION AND RECOMMENDATIONS

The results obtained from this study, which was conducted to determine the irrigation water quality of water resources (wells) used in some agricultural lands in Konya-Çumra-Alemdar Neighborhood, are summarized below:

4.1 Conclusion:

1) The EC values of water samples taken from irrigation water resources were generally above 750 µmhos/cm. In agricultural lands irrigated with irrigation water (C_3) samples exceeding the threshold water salinity, salt-tolerant plants may need to be preferred, and special measures may be required to control salinity. In the study, EC values were found to range between 580 and 1150 µmhos/cm, while pH values ranged between 7.11 and 8.12. Irrigation water salinity classes were identified as C_2S_1 (moderately saline - low alkaline) and C_3S_1 (highly saline - low alkaline).

2) In terms of water-soluble anions and cations, irrigation water samples were rich in Ca cation and SO_4 anion. Sodium adsorption ratios (SAR) ranged from 0.51 to 1.29. Sodium percentages ranged from 10.22 to 23.91, and boron concentrations in all samples were found to be below the threshold boron level of 0.7 ppm.

3) The salinity levels of irrigation water in the study area were generally found to be high. Such a case may cause salinity problems in agricultural areas where these waters are used.

4.2 Recommendations:

1) To prevent salinity problems, drainage systems should be developed, and periodic maintenance should be performed on existing drainage networks.
2) Soils should be enriched with organic matter, and soil cultivation techniques should be prioritized.
3) Due to climate change in recent years, rainfall has decreased and there is a greater need for irrigation water, so it is likely that salinity and alkalinity problems will be encountered in the coming years. Therefore, leaching and reclamation efforts should be prioritized now.
4) To avoid yield losses in agricultural production, the irrigation water required by the plant must be provided using appropriate methods. Considering the limited availability of water, sprinkler and drip irrigation methods should be preferred in the region. The number of irrigations and the amount of water provided should be planned to avoid unnecessary and excessive irrigation.
5) Farmers should be made aware of soil, plant, and irrigation water quality issues through relevant educational institutions or with the assistance of relevant units in agricultural organizations.
6) In the irrigated lands where salinity, alkalinity, and boron problems are observed or may occur, the supply of high-quality irrigation water is of great importance. Therefore, further development of projects such as the KOP project will be beneficial.

REFERENCES

[1] Taş, İ., Yıldırım, Y. E., Özkay, F. & Aras, İ., 2013. Konya Ovasında Su Kalitesi ve Toprak Tuzluluğu. *Ulusal Kop Bölgesel Kalkınma Sempozyumu*, 14–16 Kasım 2013, Konya. (In Turkish)

[2] Alpaslan, K., Karakaya, G., Gündüz, F. & Koçer, M. A. T., 2016. Boztepe Recai Kutan Baraj Gölü Su Kalitesinin Değerlendirilmesi. *Türk Tarım ve Doğa Bilimleri Dergisi*, 4(1): 22–29. (In Turkish)

[3] Kaçar, K. & Tüfenkçi, Ş., 2021. Hakkari Bölgesindeki Bazı Sulama Havuzlarının Sulama Suyu Kalitesi Açısından Değerlendirilmesi. *Yüzüncü Yıl Üniversitesi Tarım Bilimleri Dergisi*, 31(1). (In Turkish)

[4] Patlar, E. B. & Yılmaz, A. M., 2025. Quality Assessments for Irrigation Waters used in Agricultural Fields of Konya - Meram Hatunsaray Neighborhood. *International Journal of Environmental & Agriculture Research (IJOEAR)*, 11(7): 45–55. ISSN: 2454-1850.

[5] Topçu, E. & Taş, İ., 2020. Sulama Suyu Kalitesi Açısından Çanakkale–Biga Ovası Yeraltı Sularının Durumu. *ÇOMÜ Ziraat Fakültesi Dergisi (COMU J. Agric. Fac.)*, 8(1): 251–260. ISSN: 2147–8384 / e-ISSN: 2564–6826. doi:10.33202/comuagri.732685. Çanakkale. (In Turkish)

[6] Demer, S. & Hepdeniz, K., 2018. Isparta Ovasında (GB-Türkiye) Sulama Suyu Kalitesinin İstatistik ve Coğrafi Bilgi Sistemleri Kullanılarak Değerlendirilmesi. *Türk Coğrafya Dergisi*, 70: 109–122. (In Turkish)

[7] Avcı, O. & Yılmaz, A. M., 2025. Quality Assessment of Irrigation Waters used in Agricultural Fields of Mersin Mezitli District and Irrigation-Induced Soil Salinity Assessments. *International Journal of Environmental & Agriculture Research (IJOEAR)*, 11(7): 81–92. ISSN: 2454-1850.

[8] Dorak, S. & Çelik, H., 2017. Irrigation Water Quality of Nilüfer Stream: Effects of the Wastewater Discharges of the Treatment Plants. *Ege Üniversitesi Ziraat Fakültesi Dergisi*, 54(3): 249–257.

[9] Akaroğlu, Ş. N. & Seferoğlu, S., 2018. Sulama Suyu Kalitesinin Çileğin (Fragaria x ananassa Duch. Rubygem) Besin Maddesi İçerikleri ve Bazı Meyve Kalite Özellikleri Üzerine Etkileri. *ADÜ Ziraat Dergisi*, 15(1): 47–54. Aydın. (In Turkish)

[10] Aregahegn, Z. & Zerihun, M., 2021. Study on Irrigation Water Quality in the Rift Valley.

[11] Ilan, S., Thevs, N. & Priori, S., 2021. Soil Salinity and Sodicity in Drylands: A Review of Causes, Effects, Monitoring, and Restoration Measures. *Frontiers in Environmental Science*, 9: 712831. doi:10.3389/fenvs.2021.712831.

[12] Anonymous, 2022(a). Konya. *Vikipedi*. Available at: https://tr.wikipedia.org/wiki/Konya (In Turkish).

[13] Anonymous, 2017. Konya İl Jandarma Komutanlığı Coğrafi Bilgiler. Available at: http://www.konya.gov.tr/il-jandarma-komutanligi-cografi (In Turkish).

[14] Bostancı, İ., 2023. Konya Kapalı Havzası Sulama Birliklerinin Sulama Yönetimindeki Etkileri ve İşletme Sorunları. Doktora Tezi, Selçuk Üniversitesi Fen Bilimleri Enstitüsü, Konya. (In Turkish).

[15] Anonymous, 2020. Peyzaj Alanlarının Drenajı. Available at: http://sulamatr.com/peyzaj-alanlarinin-drenaji/ (In Turkish).

[16] Anonymous, 2022(b). Çumra İlçe Milli Eğitim Müdürlüğü. Available at: https://cumra.meb.gov.tr/ (In Turkish).

Assessment of Socio-Economic Impact of Flood: Evidence from Semi-urban Areas of Ile-Ife, Osun State, Nigeria

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Abstract**—** *This study assessed the socio-economic impact of floods in semi-urban areas of Ile-Ife, Osun State, Nigeria, to identify the causes of flooding in the rural areas and the adaptation mechanisms employed by people in the study area. The study was carried out in the semi-urban areas of Ile-Ife (Esinmirin and Omirin, Eleyele, Ogbon-Agbara, and Akarabata) with a population size of three hundred and sixty-six (366) households, out of which one hundred and seventy-five (175) households constituted the sample size of the study. Slovin's formula was used to determine the sample size. The data were obtained through the administration of questionnaires to the respondents, and the data collected were analyzed using descriptive statistics such as frequency and percentage counts. The results obtained from the study showed that improper drainage systems (81.1%), waste dispositions into the stream (79.5%), buildings on the floodplain (93.7%), and improper building layout (76.5%), respectively, are the major causes of flooding in the study areas. The study also established that improved and respected building structures and codes (80.5%), packing of valuable properties to an area not affected by flood (80.6%), and also use of a protected wall to reduce the speed of flood water (53.3%), respectively are the adaptation mechanism employed in the study areas. The study concluded that the improper building layout, encroachment of flood plain, improper drainage systems, and lack of proper waste disposal centers are the factors responsible for flooding in the study areas.*

Keywords**— *Flood, Socio-economic, Perception, Awareness, and Adaptation.***

I. INTRODUCTION

Flood is a notable natural disaster that can severely damage an area's social, economic, and infrastructural facilities and innovation (Rahman *et al*., 2020). Flooding is defined as an overabundance of water flowing onto normally dry land (Djimesah *et al.*, 2018), for example, when rainfall surpasses the soil's absorptivity, resulting in substantial environmental implications (Nwachukwu *et al.*, 2018). Flooding has become more common in recent years, with 70 % of the population worldwide exposed to flooding each year and over 800 million residing in flood-prone areas (Kundzewicz *et al*., 2014; Andreadis *et al*., 2022). During 1-in-100-year flood events, 1.47 billion people, or 19% of the world's population, are directly exposed to noteworthy risks (Johnson, 2023). Natural factors that contribute to flooding include heavy rainfall, storms, and hurricanes (Salhab, 2024). Human factors include land use changes such as urbanization and deforestation, which can increase the amount of runoff and make it harder for water to be absorbed into the ground (Alshammari *et al*., 2023). Climate change also plays a role, as it can cause sea levels to rise and lead to more frequent and severe floods (Das and Swain, 2024). Additionally, inadequate infrastructure and poor land-use planning can also contribute to flooding in developing countries (Umar and Gray, 2022).

Overflowing rivers flood one-fifth to one-third of the country each year during the pre-monsoon (April to May) and monsoon (June to September) seasons (Rahman, 2019). These floods cause physical damage to crops, buildings, and other infrastructure, along with social disruptions and both direct and indirect monetary losses (Baky *et al*., 2020; Abubakar *et al*., 2020). Flooding has been the most common natural hazard in Africa over the last decade, and Nigerians have experienced two major floods in the past 50 years, in 2012 and 2018 (Umar and Gray, 2022). Flood hazards are considered among the most significant natural disasters in terms of human impact and economic loss (Jonkman, 2005; Yu *et al*., 2022). Developing countries, especially those in Africa, face substantial challenges in managing floods (Anwana and Owojori, 2023). While developed nations have emphasized flood control and prevention, many developing countries, such as Nigeria, still struggle with this issue (Olawuni *et al*., 2015; Eneh *et al*., 2024). Adeloye and Rustum (2011) also examined urban flooding in Nigeria and found that human activities, including deforestation, indiscriminate waste dumping, and floodplain encroachment, are more significant contributors to the problem than climate change.

Flood disasters, according to Olawuni *et al*. (2015) and Aslam *et al*. (2021), are aided by ethically questionable human activities along the floodplain. (Garg, 2010) believes that flood losses are measurable in monetary units and that they can include livestock and cattle losses, as well as personal damage to property. Furthermore, disaster reduction, contingency planning, and prevention must consider socioeconomic factors in addition to geological and meteorological aspects. Flood disasters in Nigerian cities and towns in recent years have caused great concern and challenges for residents, governments, and researchers (Aderogba, 2012). Since August 8, 2011, the government of Osun (Osun Defender, 2011) has listed Ile-Ife town as one of the state's flood-prone areas due to floods that occur every year during the rainy season. Esinmirin and Omirin, Eleyele, Ogbon-Agbara, and Akarabata are the locations listed in Ile-Ife. As a result, the continuous occurrence of flooding in Ile-Ife virtually every year has prompted the need to investigate the socioeconomic impact of flooding in the areas.

Much of the research on flooding in Nigeria has indeed focused on urban areas such as Ibadan, Port Harcourt, and Lagos. However, it is also important to consider the possibility of floods in rural settings, as these areas may be more vulnerable due to factors such as a lack of infrastructure and resources to mitigate and respond to flooding. Factors such as improper channeling of drainage, floodplain encroachment, deforestation, and indiscriminate dumping of refuse contribute to urban flooding, but different or additional factors may be responsible for flooding in semi-urban or rural areas. Therefore, conducting research in these areas is crucial for understanding the potential risks and developing effective strategies for flood management and disaster response in Nigeria. This research, therefore, strictly focuses on the factors responsible for the flood, socio-economic impacts, perception, awareness levels, and the adaptation mechanisms of the populace in the Semi-Urban areas of Ile-Ife, Osun State, Nigeria.

II. RESEARCH DESIGN AND METHODOLOGY

2.1 Study design:

The study employed a quantitative approach. The study was conducted in four (4) different locations in semi-urban areas of Ile-Ife town, Osun State, Nigeria, and those locations were selected because they are flood-prone areas that experience floods every year during the rainy season. The study data were derived from fieldwork involving the administration of a questionnaire.

2.2 Sample population:

All households of the semi-urban area of Ile-Ife constituted the population for the study. Ile-Ife is located between latitudes 7°28′N and 7°45′N and longitudes 4°30′E and 4°34′E with a population of 501,952 residents. The following areas are purposively selected as the sample sites; (Esinmirin and Omirin, Eleyele, Ogbon-Agbara, and Akarabata) Ile-Ife. Figure 1 indicated map of Ile-Ife, Osun State and their coordinates were obtained using hand-held global positioning system (GPS).

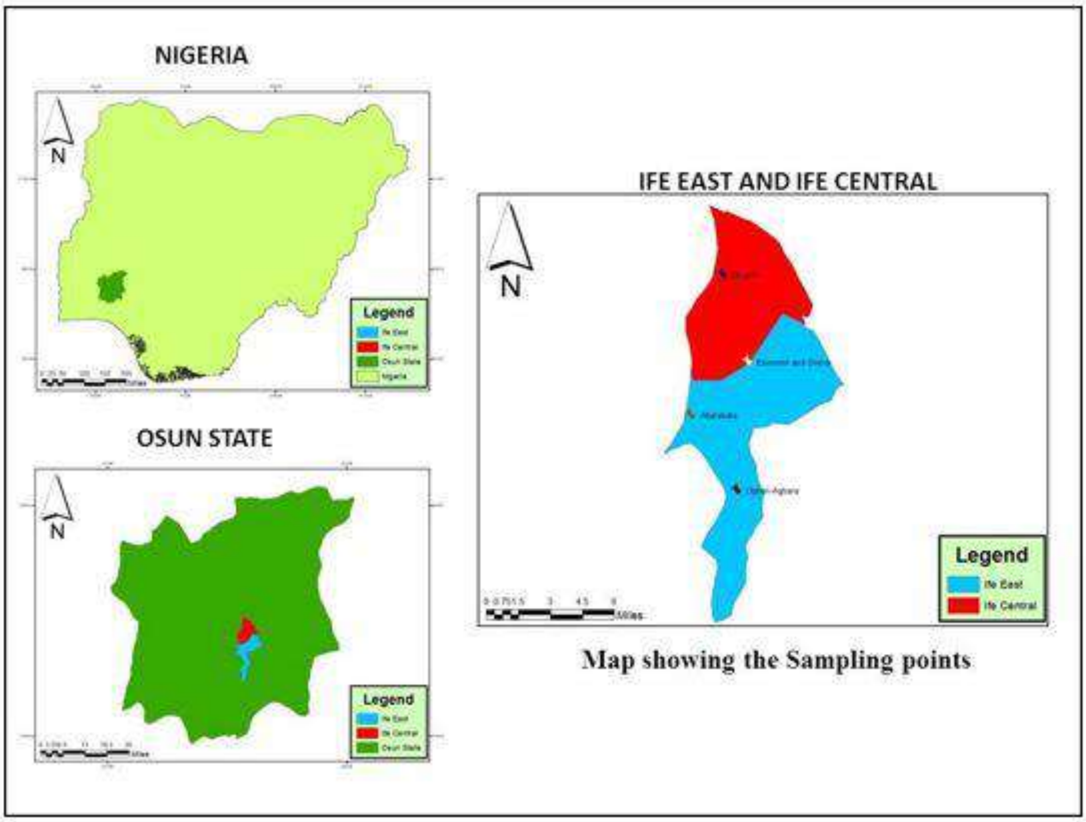

FIGURE 1: Map of Nigeria, Osun State, and study areas in Ife East and Ife Central

2.3 Sample size determination:

Based on the aim of this study in assessing the socio-economic impact of flood in four different locations of Ile-Ife semi-urban areas, the sample size was determined with the use of slovin's formula. The size of the sample in each location was chosen in relation to the household total population size of the area.

Slovin's formula,

$$n = \frac{N}{1+Ne^2} \quad (1)$$

Where n= Number of samples; N= Total population and e= Error tolerance at confidence level of 95% (0.05 margin error) and the population size of the household in the study areas was Three hundred and sixty-six (366), out of which one hundred and seventy-five (175) were the sample size based on the above formula at 95% confidence level.

2.4 Data collection:

The data was obtained through fieldwork involving the administration of questionnaires to one hundred and seventy-five (175) respondents from four (4) different sample household locations of semi-urban areas of Ile–Ife, Osun State, Nigeria, which were randomly sampled are Esinmirin and Omirin 140(76), Eleyele 70(33), Ogbon-Agbara 104(50), and Akarabata 104(50).

2.5 Data analysis:

Data collected were coded and entered into SPSS Windows version 20, and the data were analyzed through the use of descriptive statistics such as frequency counts and percentage counts.

III. RESULTS

3.1 Demographic distributions of the respondents in the semi-urban areas of Ile-Ife:

The demographic distributions of the respondents in the semi-urban areas of Ile-Ife are presented in Table 1. The results showed that (61.1%) of respondents were male. The findings also showed that the majority of the respondents (44.6%) were between the ages of 46 and 60 years. Most of the respondents did not have a formal education (32.0%), while 29.1% and 14.3% of them had secondary education and tertiary education, respectively. The result indicated that the majority of the respondents (29.1%) had lived in the community for about 11-15 years. The study showed that 66.9% of the respondents are christians. The relative proportion of the respondents in percentage frequency of the sample locations of the respondent is as follows, Esinmirin and Omirin 67 (33.3%), Eleyele 33 (18.9%), Ogbon- agbara 50 (28.6%), and Akarabata 25 (14.3%). The result showed that most of the respondents (78.3%) are married. This indicates that the majority of the respondents have those they are responsible for, i.e., families

TABLE 1
SOCIO-DEMOGRAPHIC CHARACTERISTICS OF RESPONDENTS IN THE SEMI-URBAN AREAS OF ILE-IFE

Variables	Levels	Frequency	Percentage (%)
Sex	Male	107	61.1
	Female	68	38.9
Age	16-30 years	6	3.4
	31-45 years	32	18.3
	46-60 years	78	44.6
	61-75 years	51	29.1
	76-90 years above	8	4.6
	Total	175	100
Educational level	No formal	56	32.0
	Primary	23	13.1
	Vocational	20	11.4
	Secondary	51	29.1
	Tertiary	25	14.3
	Total	175	100
No of years in the community	< 5 years	22	12.6
	6-10 years	45	25.7
	11-15 years	51	29.1
	16-20 years	23	13.1
	Above 20 years	34	19.4
Religion	Christianity	117	66.9
	Islam	49	28.0
	Traditional	9	5.1
Sample’s location	Esinmirin and Omirin	67	38.3
	Eleyele	33	18.9
	Ogbon-Agbara	50	28.6
	Akarabata	25	14.3
Marital Status	Single	12	6.9
	Married	137	78.3
	Widow	25	14.3
	Divorced	1	0.6
	Total	175	100

3.2 Sources of livelihood of people in the semi-urban areas of Ile-Ife:

The sources of livelihood of people in the semi-urban areas of Ile-Ife are presented in Table 2. The study showed that trading (32.6%) is the most common livelihood activity, followed by farming (24.0%) and civil service (12.6%) of the people in the study areas. Other prominent livelihoods comprise handicraft and tailoring, with each accounting for 6.9%, whereas clerical work (5.1%), teaching (4.6%), and bricklaying (2.9%) signify reduced proportions. The least common sources of livelihood of people in the study areas include hairdressing, with 0.6% of the total respondents. The results indicated that 4.0% of the total respondents living in the study areas engaged in other sources of livelihood.

Generally, the findings indicated that people in the study areas engaged in different occupations as their sources of livelihood, with a substantial dependence on informal commercial practices, mainly trading and farming, which in total gave 56.6% of the total respondents to the source of livelihood of people in the semi-urban areas of Ile-Ife.

TABLE 2
PERCENTAGE FREQUENCY OF THE RESPONDENT SOURCE OF LIVELIHOOD OF PEOPLE IN THE SEMI-URBAN AREAS OF ILE-IFE

Means of Livelihood	Frequency	Percent
Civil service	22	12.6
Trading	57	32.6
Farming	42	24.0
Teaching	8	4.6
Tailoring	12	6.9
Hairdressing	1	0.6
Bricklaying	5	2.9
Handicraft	12	6.9
Cleric	9	5.1
Total	168	96.0
Others	7	4.0
Total	175	100.0

3.3 Possible factors responsible for flooding in the semi-urban areas of Ile-Ife:

The possible factors responsible for flooding in the semi-urban areas of Ile-Ife, Osun State, Nigeria are presented in Table 3. The results of the findings indicated that (93.7%) of the total respondents agreed that there is no proper drainage system in their area. The majority of the respondents (70.9%) strongly disagreed with the fact that waste is always been disposed of into the stream in their houses. Most of the respondents (75.4%) agreed that the closeness of houses to the stream/river in their area contributes to flooding activities. The result of the study also indicated that the majority of the respondents (72.6%) disagreed that land in their area is cheaper compared to other locations in the community. The results also reveal that most of the respondents (61.1%) disagreed that the land in their area is close to the commercial center of the town. (95%) of the respondents disagreed that their area was overpopulated.

From the study, 81.1% of the respondents disagreed that the land where they built their house is an inheritance. The majority of the respondents (96.6%) disagreed with the carefree attitude toward drainage system management. Most of the respondents (54.9%) disagreed with the fact that there are no drainage systems at all in their area. The results from the study showed that the majority of the respondents (93.7%) agreed that their house was situated on the floodplain. The study revealed that the majority of the respondents (89.7%) agree that there are no proper waste disposal centers in their area. Some of the respondents (76.5%) agreed that flooding in their area is a result of improper building layout, the study maintained.

TABLE 3
POSSIBLE FACTORS RESPONSIBLE FOR FLOODING IN THE SEMI-URBAN AREAS OF ILE-IFE

Factors	Percentage Level of Response			
	Strongly Agree	Agree	Strongly Disagree	Disagree
No proper drainage systems	81.1	12.6	5.1	1.1
Waste disposed into the stream	5.7	13.7	70.9	8.6
Closeness of house to the stream/ river	56	19.4	18.9	5.1
Cheapness of land	4.6	22.9	61.7	10.9
Land closeness to the commercial center	5.1	33.7	52	9.1
Overpopulation	0	4.6	73.7	21.7
Land is an inheritance	1.7	16.6	65.1	16
Care free attitude to drainage management	0.6	2.9	73.7	22.9
Absence of drainage systems	29.7	12.6	12.6	42.3
Building house on the flood plain	73.1	20.6	4.6	1.1
No proper waste disposal center	6.3	83.4	9.7	0.6
Improper building layout	25.1	51.4	18.3	5.1

3.4 Socio-economic impact of flood in the semi-urban areas of Ile-Ife:

The socio-economic impact of flood in the semi-urban areas of Ile-Ife, Osun State, Nigeria is presented in Table 4. The result revealed that (57.7%) of the respondents' businesses/means of livelihood have been affected by the flood. The findings also show that (82.9%) of the respondents had fall victim to a reduction in their household income due to the menace of a flood. It was revealed that the majority (93.7%) of the respondents spent more money on their houses due to the activities of the flood. The findings show that the majority of the respondents (97.1%) have not lost any of their households to flood activities. The result revealed that (93.7%) of the respondents engaged themselves in economic activities to prevent flood activities from affecting their properties.

The majority of respondents' households (77.7%) have not received support from the government. It was revealed that (79.4%) of the respondents do not have access to any form of credit in supporting either their business or managing the impact of a flood on their means of livelihood. The results revealed that a larger percentage of the respondents (84%) had not borrowed money to solve flood problems. The majority of the respondents (86.9%) consider living in their area risky. The study also revealed that (89.7%) of the respondents consider owning a property in their area risky. The result of the findings also shows that (85.7%) of the respondents were battling with flooding and are unable to move their business due to financial constraints. The study revealed that (97.7%) of the respondents agreed that the cost of living is affected by the flood.

TABLE 4
RESPONDENTS' LEVELS OF RESPONSE TO THE SOCIO-ECONOMIC IMPACT OF FLOOD, IN THE SEMI-URBAN AREAS OF ILE-IFE

Questions	Percentage Level of Response (n=175)			
	Freq	YES (%)	Freq	NO (%)
Business/means of livelihood Affected	101	57.7	74	42.3
Properties have been destroyed	162	93.2	12	6.9
Household income affected	145	82.9	30	17.1
Increased house maintenance cost	164	93.7	11	6.3
Caused death	5	2.9	170	97.1
Engaged in Preventable practices	164	93.7	11	6.3
Government assistance	39	22.3	136	77.7
Access to credit	36	20.6	139	79.4
Used loan for financing loss	28	16	147	84
High risk of living in the area	152	86.9	23	13.1
Highly risky in owning property in the area	157	89.7	18	10.3
Business relocation	25	14.3	150	85.7
The increased cost of living	171	97.7	4	2.3

3.5 The perception, awareness, and adaption mechanisms to flood in the semi-urban areas of Ile-Ife:

The perception, awareness, and adaption mechanisms to flood in the semi-urban areas of Ile-Ife, Osun State, Nigeria are presented in Table 5. The results of the findings revealed that the majority of the respondents (93.8%) disagreed that flood is a normal occurrence. The majority of the respondents (94.9%) were against the opinion that a proper drainage system would not be able to stop the activities from the flood. The majority of the respondents (69.8%) disagreed that the increase in population contributed to flooding occurrence. This shows that flood action in the study area was not a result of an increase in population. The majority of the respondents (95.5%) believed that it is not too early to discuss floods as a real problem. Most of the respondents (94.9%) disagreed that flood action in their area is a result of supernatural power or maybe the gods were angry.

TABLE 5
RESPONDENTS' PERCEPTION LEVELS OF FLOOD IN THE SEMI-URBAN AREAS OF ILE-IFE

Perception Levels	The percentage level of Response (n=175)			
	Strongly Agree	Agree	Strongly Disagree	Disagree
Flood is a normal occurrence	2.9s	3.4	70.9	22.9
The proper drainage system cannot control flooding	1.7	3.4	70.3	24.6
Flooding is due to population growth	0	30.3	54.9	14.9
Early to discuss flood as a real problem	2.9	1.7	62.9	32.6
Flooding is due to supernatural power.	0.6	4.6	52.0	42.9

3.6 Awareness levels to flood in the semi-urban areas of Ile-Ife:

The awareness levels to flood in the semi-urban areas of Ile-Ife are presented in Table 6. The result showed that the majority of the respondents (95.8%) agreed that, they were aware that flood could cause loss of life. Most of the respondents (62.9%) disagreed that; the recent flood in the study locations is a result of the dumping of refuse into the stream and waterways. The majority of the respondents (59.4%) agreed that building houses close to the stream and rivers is the major cause of flood in their area. A very little number of the respondents (10.9%) agreed while the majority of the respondents (89.1%) disagreed that they were uncertain about flood occurrences. This indicates that the majority of the respondents knew much and they were certain about the occurrence of flood. The majority of the respondents (98%) agreed to the fact that flood is a real problem.

TABLE 6
RESPONDENTS AWARENESS LEVELS TO FLOOD IN THE SEMI-URBAN AREAS OF ILE-IFE

Awareness Levels	Percentage level of Response (n=175)			
	Strongly Agree	Agree	Strongly Disagree	Disagree
Flood can cause loss of live	50.9	44.9	3.4	1.1
Flooding is due to dumping of refuse into the stream and water ways.	12.6	24.6	54.3	8.6
Building proximity to stream and rivers is the major cause of flood	42.3	17.1	28.0	12.6
Uncertain on flood occurrences	4.6	6.3	57.1	32.0
Flood is a real problem	86.9	11.1	0.6	1.1

3.7 Adaptation mechanism to flood in the semi-urban areas of Ile-Ife:

The adaptation mechanism to flood in the semi-urban areas of Ile-Ife are presented in Table 7. The findings revealed that the majority of the respondents (56%) disagreed that, they would have to leave their house when rain is about to start and returned after the rainfall while the remaining (24%) agreed to this fact. The majority of the respondents (80.6%) agreed that they always adopt the adaptation mechanism of packing valuable properties to their relative's houses in another part of the community which were not been affected by flood while the remaining (19.4%) disagreed with this adaptation mechanism. Most of the respondents (80.2%) agreed that improving building structures and respecting building codes of conduct would prevent their houses from being damaged by flood while the remaining (19.4%) disagreed with this. The result revealed that the majority of the respondents (93.2%) agreed that the use of a protected wall would reduce the water speed from the flood.

TABLE 7
RESPONDENTS' ADAPTATION MECHANISM TO FLOOD IN THE SEMI-URBAN AREAS OF ILE-IFE

Adaptation Mechanism	The percentage level of Response (n=175)			
	Strongly Agree	Agree	Strongly Disagree	Disagree
Leaves house when it's about to rain and comes back after the rain	21.1	22.9	32.6	23.4
Valuable properties are packed to an area not affected by flood	38.9	41.7	14.3	5.1
Improved and respected building structures and codes.	33.1	47.4	17.7	1.7
Protected wall to reduce floodwater	50.3	42.9	5.1	1.7

IV. DISCUSSION

The relative proportion of the respondents in percentage frequency of the sample locations of the respondent is as followed Esinmirin and Omirin 67 (33.3%), Eleyele 33 (18.9%), Ogbon- agbara 50 (28.6%), and Akarabata 25 (14.3%). This study showed that children and women are more likely to be susceptible to flood which align with the finding of Ariyabandu and Wickramasighe (2005) and Bradshaw and Fordham (2018), who reported that women and children are more susceptible to flood. The marital status of any individual respondent in a household serves as a very important indicator in determining the socioeconomic power of a respondent (Yande, 2009). This study agrees with the report of Brouwer *et al.* (2007) and Parvin *et al.* (2016) who stated that the hardest hits by flood disasters are the poor people who also have very little capacity to cope with the loss of property and income.

Flooding in semi-urban Ile-Ife is basically ascribed to poor land-use planning and inadequate drainage infrastructure. This agreed with the fact that flood disasters are aided by unethical human activities along the flood plain (Olawuni *et al*., 2015; Mitrović *et al*., 2019). Generally, the respondents identified lack of proper waste disposal systems and nearness to floodplains as main contributors to flood risk (Wantim *et al*., 2023). In contrast to notions that, factors such as proximity to commercial hubs, inheritance of land, and overpopulation were not seen as main causes of flooding in the study areas. The building of residential houses near waterways and Inappropriate building aggravate water runoff and decrease natural penetration. The findings agree with recent studies signifying that urban development into zones that are prone to flood, together with feeble environmental mismanagement and institutional planning, deepens flood vulnerability in Nigerian metropolises (Adeloye and Rustum, 2011; Lorie *et al*., 2020; Higuera Roa *et al*., 2022; Aiyewunmi, 2023). The study indicated that the larger percentage of the total respondents' businesses/means of livelihood have been affected by the flood. This agreed with (Theron, 2007; Gizaw and Baye, 2025) that floods could destroy means of livelihood such as houses, roads, farms, crops, cattle, and livestock. This study proved that effective flood mitigation must therefore address public infrastructure development, spatial planning and drainage management.

Flooding in semi-urban Ile-Ife imposes significant socio-economic problems on the households that were affected. The interruption of livelihoods and amplified household expenses cause a decline in economic firmness. This implies that floods had brought financial difficulties to the occupants of this flood-prone areass in the semi-urban area of Ile-Ife, and the study was in line with (Nott, 2006; Ngwira and Bag, 2017), which stated that physical property damage is one of the major causes of tangible loss in floods. Inadequate financial capability hinders residents from moving or securing defensive infrastructure, which aligns with the report by Lindsell and Prater (2003) and Jha *et al*. (2011). The absence of government backing and access to credit aggravates these vulnerabilities. Numerous residents participate in self-driven flood mitigation despite systemic neglect. The risk perception backing property ownership and residence in flood-prone zones signifies growing environmental uncertainty. These encounters indicate wider trends in Nigerian, where flooding intensifies penury and limits resilience (Amadi *et al*., 2023). Also, insufficient institutional funding and financial elimination deepen the long-term effects (Finucane *et al*., 2020).

Residents of semi-urban areas of Ile-Ife showed a high level of awareness concerning the causes and implications of flooding. This agrees with Slovic (1987) and Ali *et al*. (2022) report, who stated that the knowledge of risk perception is supported as a prerequisite for achieving effective risk communication. The largest percentage of the respondents disagree with traditional views and supernatural accounts as a cause of flooding, indicating a change toward reasoning and environmental literacy that is scientific in nature. This indicates that the majority of the respondents do not believe in any superpower or gods as the main cause of flooding in their area, this finding disagrees with the report of Mustapha (2002) and Bempah and Øyhus (2017). They also uphold the efficacy of good drainage system in flood management, showing a solid understanding of structural adaptation approaches. The perception that flooding is not a normal or inevitable incident indicates growing concern over its human sources. In contrast to the notion that population growth is not broadly perceived as a main flood driver, indicating a necessity to focus on planning and infrastructure failures. The urgency stated by inhabitants in tackling flooding similar with wider demands for practical risk communication. These studies support previous research highlighting the role of awareness and perception in shaping community resilience (Ansari *et al*., 2022; Savari *et al*., 2025). Integrating homegrown knowledge and perceptions is crucial in designing comprehensive flood management approaches in the semi-urban areas of Nigeria.

Residents of the semi-urban areas of Ile-Ife show a high awareness of the risks posed by flooding, mainly its possibility to cause loss of life, and this agrees with the report of Abegaz *et al*. (2024), who stated that floods can cause serious loss of life. The denunciation of misrepresentation, such as ascribing flooding to waste dumping alone, shows a nuanced understanding of manifold contributory factors. Many appropriately acknowledged the nearness to waterways as a noteworthy contributor, indicating a sound grasp of spatial flood risks. The stout agreement that flooding is a real and pressing issue agrees with findings highlighting the increasing awareness in flood-prone regions in Nigeria (Savari *et al*., 2025). Such awareness is vital for determining adaptive behavior and policy engagement.

Flood adaptation strategies among residents of semi-urban Ile-Ife show an integration of structural, behavioral, and community-based responses. Though brief dislodgment during rainfall is least favoured, many depends on moving valuables items to safer places within the municipal. This agreed with Madhani and Jay (2011) and Esariti *et al*. (2023), who reported that the timely evacuation of people and property from the flood-prone area is one of the major adaptation mechanisms against flood menace. Structural adaptations, such as strengthening buildings and obeying codes of construction, are extensively known as efficient measures. This implies that the use of a protected wall has been the stronghold in preventing the impact of flood water in the study area (Xian *et al.* 2018; Ogie *et al.*, 2020). The usage of defensive barriers to reduce water flow is also a usual practice, signifying an understanding of flood dynamics. These findings are consistent with the studies that highlight household-level resilience through informal practices and low-cost structural interventions to curb floods menace (Oukes *et al*., 2022; Tan *et al*., 2024). Encouraging obedience to building regulations and community-based planning could improve long-term flood resilience in the semi-urban areas of Ile-Ife, Osun State, Nigeria.

V. CONCLUSION

This study assessed the Socio-Economic Impact of Flood in Ile-Ife, Osun State, Nigeria. The analysis revealed that improper building layout, encroachment of flood plain, improper drainage systems, and lack of proper waste disposal centers are some of the factors responsible for flooding in the study area. The study also established that the cost and standard of living were affected by flood and that use of a protected wall would prevent the activities of flood in the study area.

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Not Applicable

CONSENT TO PARTICIPATE

Not applicable

CONSENT TO PUBLISH

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REFERENCES

[1] Amadi, U. E., Ibe-Enwo, G. I. and Odoh, T. A. (2023). Nnubuogu Arthur-Kenneth Eloka 4 Department of Public Administration; 4 Department of Marketing Akanu Ibiam Federal Polytechnic Unwana, Ebonyi State, Nigeria.

[2] Abubakar, B., Umar, H., Barde, M. M. and Adamu, S. (2020): Socio-economic Impact of Flooding on the Riverine Community of River Benue in Adamawa State, Nigeria. Futty *Journal of the Environment*, 14(2), 116-124.

[3] Adeloye, A. J. and Rustum, R. (2011). Lagos (Nigeria) flooding and influence of urban planning, *Urban Design and Planning*, 164 (3), 185 – 187.

[4] Ali, A., Rana, I. A., Ali, A. and Najam, F. A. (2022). Flood risk perception and communication: The role of hazard proximity. *Journal of environmental management*, *316*, 115309.

[5] Alshammari, E., Rahman, A. A., Rainis, R., Seri, N. A. and Fuzi, N. F. A. (2023). The impacts of land use changes in urban hydrology, runoff and flooding: a review. *Current Urban Studies*, *11*(1), 120-141.

[6] Andreadis, K. M., Wing, O. E., Colven, E., Gleason, C. J., Bates, P. D. and Brown, C. M. (2022). Urbanizing the floodplain: global changes of imperviousness in flood-prone areas. *Environmental Research Letters*, *17*(10), 104024.

[7] Ariyanbandu, M.M. and Wackramasinghe, W.M. (2005): Gender Dimension in Disaster Management: A guide for South Asia: Sri Lanka.

[8] Aderogba, K.A. (2012a). Qualitative Studies of Recent Floods and Sustainable Growth and Development of Cities and Towns in Nigeria. *International Journal of Academic Research in Environmental and Management Sciences*, 1 (3), 1-25.

[9] Aiyewunmi, T. (2023). *Challenges and potential solutions to pluvial flood risk in urban tropical African communities, a case study using Ijebu-Ode, in South West Nigeria* (Doctoral dissertation, University of Liverpool).

[10] Amadi, U. E., Ibe-Enwo, G. I. and Odoh, T. A. (2023). Nnubuogu Arthur-Kenneth Eloka 4 Department of Public Administration; 4 Department of Marketing Akanu Ibiam Federal Polytechnic Unwana, Ebonyi State, Nigeria.

[11] Ansari, M. S., Warner, J., Sukhwani, V. and Shaw, R. (2022). Implications of flood risk reduction interventions on community resilience: An assessment of community perception in Bangladesh. *Climate*, *10*(2), 20.

[12] Anwana, E. O. and Owojori, O. M. (2023). Analysis of flooding vulnerability in informal settlements literature: mapping and research agenda. *Social Sciences*, *12*(1), 40.

[13] Aslam, A., Parthasarathy, P. and Ranjan, R. K. (2021). Ecological and societal importance of wetlands: a case study of North Bihar (India). *Wetlands conservation: current challenges and future strategies*, 55-86.

[14] Baky, M. A. A., Islam, M., and Paul, S. (2020). Flood hazard, vulnerability and risk assessment for different land use classes using a flow model. *Earth Systems and Environment*, *4*(1), 225-244.

[15] Bempah, S. A. and Øyhus, A. O. (2017). The role of social perception in disaster risk reduction: Beliefs, perception, and attitudes regarding flood disasters in communities along the Volta River, Ghana. *International journal of disaster risk reduction*, *23*, 104-108.

[16] Bradshaw, S. and Fordham, M. (2018). Impact of Floods on the Socio-economic Livelihoods of Women and Girls in the Lower Shire in Southern Malawi at www. academia. edu. *Accessed on*, *30*.

[17] Brouwer, R., Akter, S., Brander, L. and Haque, E. (2007). Socioeconomic vulnerability and adaptation to environmental risk: a case study of climate change and flooding in Bangladesh. *Risk Analysis: An International Journal*, 27(2), 313-326.

[18] Dama, F, M, Ishaku H, T. and Abdurrahman, B, I. (2014). Analysis of the Determinants of Floods in Numan Town,Nigeria. *Journal of Environmental Science and Engineering*, 3; 264-273.

[19] Das, A. and Swain, P. K. (2024). Navigating the sea level rise: Exploring the interplay of climate change, sea level rise, and coastal communities in india. *Environmental Monitoring and Assessment*, *196*(11), 1010.

[20] Djimesah, I.E. Okine, A.N.D., and Mireku, K.K., 2018, Influential factors in creating warning systems towards flood disaster management in Ghana: An analysis of 2007 north-ern flood. *International Journal of Disaster Risk Reduction* 28; 318–326. doi: 10.1016/j. ijdrr.2018.03.012.

[21] Eneh, N. E., Adeniyi, A. O., Akpuokwe, C. U., Bakare, S. S. and Titor-Addingi, M. C. (2024). Evaluating environmental legislation on disaster resilience: Data insights from Nigeria and the USA. *World Journal of Advanced Research and Reviews*, *21*(2), 1900-1908.

[22] Esariti, L., Handayani, W. and Purnomo, M. S. (2023). Adaptation strategies of flood prone urban settlement of tegal city. In *IOP Conference Series: Earth and Environmental Science* (Vol. 1268, No. 1, p. 012048). IOP Publishing.

[23] Finucane, M. L., Acosta, J., Wicker, A. and Whipkey, K. (2020). Short-term solutions to a long-term challenge: Rethinking disaster recovery planning to reduce vulnerabilities and inequities. *International journal of environmental research and public health*, *17*(2), 482.

[24] Garg, S.K. (2010). Hydrology and Water Resources Engineering. Delhi: Khanna Publishers.

[25] Higuera Roa, O., O'Connor, J., Ogunwumi, T. S., Ihinegbu, C., Reimer Lynggaard, J., Sebesvari, Z. and Koli, M. (2022). Technical Report: Lagos floods.

[26] Gizaw, T. D. and Baye, S. (2025). Flood Effects on Household Livelihoods and it's Controlling strategies in Gelana Woreda, Oromia, Ethiopia. *Natural Hazards*, *121*(2), 2213-2244.

[27] Jha, A., Lamond, J., Bloch, R., Bhattacharya, N., Lopez, A., Papachristodoulou, N., Bird, A., Proverbs, D., Davies, J. and Barker, R. (2011). Five feet high and rising: cities and flooding in the 21st century. *World Bank Policy Research Working Paper*, (5648).

[28] Johnson, S. (2023). *Global assessment of flood impacts on emergency service provision to vulnerable populations, presently and under climate change* (Doctoral dissertation, Loughborough University).

[29] Jonkman S.N. (2005). Global perspectives on loss of human life caused by floods; Natural Hazards, 34(2), a151-175.

[30] Kundzewicz, Z. W., Kanae, S., Seneviratne, S. I., Handmer, J., Nicholls, N., Peduzzi, P., Mechler, R., Bouwer, L. M., Arnell, N., Mach, K. and Muir-Wood, R. (2014). Flood risk and climate change: global and regional perspectives. *Hydrological Sciences Journal*, *59*(1),1-28.

[31] Lorie, M., Neumann, J. E., Sarofim, M. C., Jones, R., Horton, R. M., Kopp, R.E., Fant, C., Wobus, C., Martinich, J., O'Grady, M. and Gentile, L. E. (2020). Modeling coastal flood risk and adaptation response under future climate conditions. *Climate risk management*, *29*, p.100233.

[32] Mitrović, V. L., O'Mathúna, D. P. and Nola, I. A. (2019). Ethics and floods: a systematic review. *Disaster medicine and public health preparedness*, *13*(4), 817-828.

[33] Mustafa, D. (2002). Linking Access and Vulnerability: *Journal of Perceptions of Irrigation and Flood Management in Pakistan*, 34 (1), 94-105.

[34] Lindsell, K. M. and Prater, S. C. (2003). Abstract on "Assessing Community Impacts of National Disasters", *National Hazard Review*, *4*(4),176-178.

[35] Ngwira, N. and Bag, P. (2017). A Study of Floods in Iponga Area, Karonga District: Causes, Impacts and Coping Strategies.

[36] Nott, J. (2006). Extreme Events: A Physical Reconstruction and Risk Assessment. Cambridge University Press. New York.

[37] Ogbonna, D. N., Amangabara, G. T. and Itulua, P. A. (2010). Study of the Nature of Urban Flood in Benin City, Edo State; Nigeria.

[38] Ogie, R. I., Adam, C. and Perez, P. (2020). A review of structural approach to flood management in coastal megacities of developing nations: current research and future directions. *Journal of Environmental Planning and Management, 63*(2), 127-147.

[39] Olawuni, O. P., Popoola, A. S., Bolukale, A. T., Eluyele, K. P. and Adegoke, J. O. (2015). An assessment of the factors responsible for flooding in Ibadan Metropolis, Nigeria. *J Environ Earth Sci*, *5*, 1-7.

[40] Osun Defender. (Osun Government) 8 August, 2011 available from> https://www.osundefender.com/.

[41] Oukes, C., Leendertse, W. and Arts, J. (2022). Enhancing the use of flood resilient spatial planning in Dutch water management. A study of barriers and opportunities in practice. *Planning Theory and Practice*, *23*(2), 212-232.

[42] Parvin, G. A., Shimi, A. C., Shaw, R. and Biswas, C. (2016). Flood in a changing climate: The impact on livelihood and how the rural poor cope in Bangladesh. *Climate*, *4*(4), 60.

[43] Rahman, A. (2019). Study on monsoon flood hazard and vulnerability assessment of old Brahmaputra river flood plain under climate change scenario.

[44] Rahman, M. M., Chowdhury, M. R. H. K., Islam, M. A., Tohfa, M. U., Kader, M. A. L., Ahmed, A. A. A. and Donepudi, P. K. (2020). Relationship between SocioDemographic Characteristics and Job Satisfaction: Evidence from Private Bank Employees. *American Journal of Trade and Policy*, 7(2), 65-72.

[45] Salhab, M. (2024). *Can data from space address critical data gaps on earth? Investigating the extent to which holistic disaster risk can be estimated using remote sensing data* (Doctoral dissertation, UCL (University College London)).

[46] Savari, M., Jafari, A. and Sheheytavi, A. (2025). Determining factors affecting flood risk perception among local communities in Iran. *Scientific Reports*, *15*(1), 4076.

[47] Slovic P. (1987): Perception of Risk. *Science*, 236(4799), 280-285.

[48] Tan, W. Y., Teo, F. Y., Chong, C. X. Y., Tan, C. Y. and Lim, C. H. (2024). Review on Lightweight Mobile Flood Wall Barrier: Way Forward for Malaysia. *J. Inst. Eng. Malaysia*, *84*(2).

[49] Theron, M. (2007). Climate change and increasing floods in Africa–implications for Africa's development [website]. *Consultancy Africa Intelligence/Africa Watch Newsletter. Viewed on March*, *19*, 2009.

[50] Strydom, H., Fouche C. B. and Delport C. S. L. (2005). Research at Grassroots for Social Sciences and Human Service Professions: Third edition.

[51] Nwachukwu, M. A., Alozie, C. P., and Alozie, G. A. (2018). Environmental and rainfall inten-sity analysis to solve the problem of flooding in Owerri urban. *Journal of Environmental Hazards*,1, 107.

[52] Umar, N. and Gray, A. (2022). Flooding in Nigeria: a review of its occurrence and impacts and approaches to modelling flood data. *International Journal of Environmental Studies*, 1-22.

[53] Wantim, M. N., Zisuh, A. F., Tendong, N. S., Mbua, R. L., Findi, E. N. and Ayonghe, S. N. (2023). Strategies and perceptions towards flood control and waste management in Limbe city, Cameroon. *Jàmbá: Journal of Disaster Risk Studies*, *15*(1), 1-14.

[54] Xian, S., Yin, J., Lin, N. and Oppenheimer, M. (2018). Influence of risk factors and past events on flood resilience in coastal megacities: Comparative analysis of NYC and Shanghai. *Science of the total environment*, *610*, 1251-1261.

[55] Yu, Q., Wang, Y. and Li, N. (2022). Extreme flood disasters: comprehensive impact and assessment. *Water*, *14*(8), 1211

Present Status of Postharvest Practices and Losses of Economically Important Fruits and Vegetables in Sri Lanka

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Abstract— *The study was conducted to find the present status of postharvest practices and losses in selected commercially grown fruits and vegetables. Economically important four and twelve vegetables were selected. A cross sectional analysis was used to analyze the present status of the postharvest practices of fruits and vegetables in the country through questionnaire survey and direct observations. Information related to the postharvest operations were collected from 1829 of main actors of the supply chain; farmers, collectors, whole sellers, transporters and retailers. Loss assessment study was performed in major six perishable supply chains in the country. Weight losses of commodities were measured at different stages and results were compared with previous findings. Most of farmers well aware about maturity indices of fruits and vegetables, and majority of them consider correct maturity for harvesting selected crops. But, 5-31 % of farmers do not consider maturity indices. Further, small scale farmers generally do not have adequate facilities to sort and grade their harvest. The close truck category is dominant in transporting majority of commodities while guava, bitter guar, long bean and potato are transported in open trucks. Only around 3% of fruits and vegetables were found transported in refrigerated trucks. Commodities are packed four types packaging methods during post harvest handling; polysack bags, plastic crates, wooden boxes and corrugated fibreboard boxes. Most of vegetables (76% in average) are still transported in polysack bags. However, 94 % of papaya is transported in plastic crates while 54 % of guava is also transported using plastic crates and corrugated fiberboard boxes. All the actors mainly use polysack bags for transporting commodities. Majority of stakeholders in Sri Lankan fruit supply chain have adopted to use safe packaging methods. Previous loss assessment studies conducted in Sri Lanka exhibited that post harvest loss of fruits and vegetables were 30 – 40%. However, according to the present study, postharvest loss of fruits remain at 15-20% and it is 20-30% in vegetables which could be considered as considerable reduction due to many programs launched during last two decades.*

Keywords— Postharvest Losses, Mechanical Damages, Packaging Methods, Supply Chain.

I. INTRODUCTION

Agriculture plays a major role in developing the countries. It directly affects on food safety and national food security. But, postharvest sector of agricultural crops still lags behind creating many problems. The postharvest loss and inappropriate postharvest practices during supply and value chains of agricultural crops leads to low prices at farm gate and high prices at consumer level as well as to low quality of produce. And also, this has led to less profit in agriculture which creates less employment or unemployment especially in rural community (Dharmathilake *et al.* 2020).

Furthermore, many intermediaries are playing an active and a major role in the supply chain of fresh commodities in Sri Lanka. Farmers, collectors, transporters, whole sellers, retailers, processors are the main actors of the supply chain and 30-40% amount of postharvest loss has been identified at each of these points (Rajapaksha *et al.* 2021). Many factors contribute to this situation. Some of them are harvesting practices, maturity at harvesting, handling and transportation, lack of storage facilities, lack of processing and value addition done, etc. (Iordachescu *et al.* 2019). Reducing this post-harvest food loss will become increasingly important over the coming decades to help sustainably feed a growing human population (Buzby and Hyman, 2012). Generation of new technologies required to rectify these malpractices is highly essential. Furthermore, transmission of technologies to relevant stakeholders is also vital in order to reduce the postharvest loss, popularize using appropriate technologies etc. However, in order to do so, proper understanding of the existing situation is a must. This will facilitate proper planning and execution of development activities and further research aimed towards the uplifting of the industry.

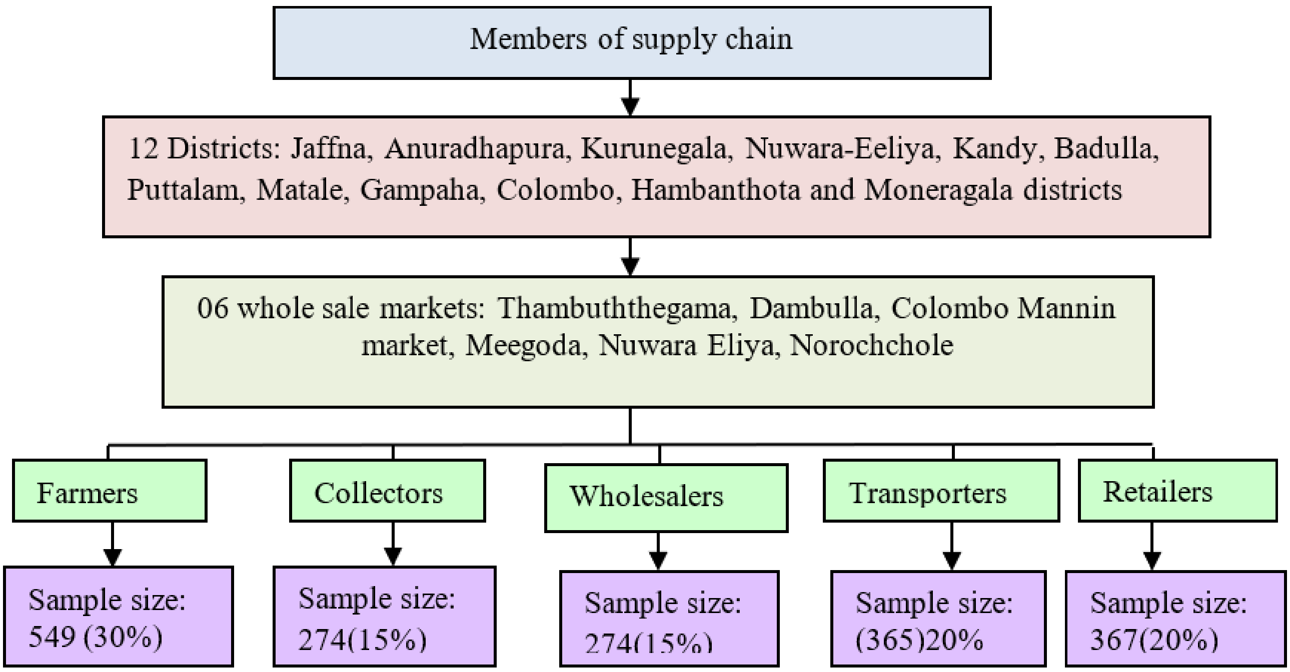
Although some of the practices are common in some crops, many vary depending on the crop, cultivation patterns, persons involved etc. During last two decades, many loss reduction measured have taken in national level and appropriate postharvest technologies have also been introduced to agriculture supply chain such as awareness creation, safe packaging and ripening methods etc. however the impact was not assessed in national level. Therefore, a more detailed study was needed to identify these postharvest practices and losses in a more generalized form which would represent the whole scenario. National Institute of Post Harvest Management (NIPHM) carried out a study on present status of postharvest practices and losses in selected commercially grown fruits and vegetables.

II. MATERIALS AND METHODS

Four economically important fruits; banana, guava, papaya, mango and twelve vegetables; carrot, capsicum, cabbage, tomato, bitter gourd, green chilli, long bean, brinjal, potato were selected for the study. Study was conducted during 2021 – 2023 years period.

2.1 Field survey:

A cross sectional analysis was taken to study the present status of the postharvest practices of fruits and vegetables in the country. The primary modes of data collection were questionnaire survey and direct observations. Data were collected via a field survey using semi-structured, pre-tested questionnaires. The details for the study were gathered from all the supply chain actors actively involved in the selected crops taken for the study. Furthermore, the postharvest practices initiating from harvesting till retail practices were also collected. The average quantities handled, handling methods, devices and equipment used, postharvest loss, etc. were also taken. Data were collected from five main categories of the supply chain; farmers (30%), collectors (10%), whole sellers (15%), transporters (15%) and retailers (30%). The study was performed on the main cultivation areas, collection areas as well as in the consumer areas of the country. The main consumer areas were Gampaha, Colombo, Kandy, Kurunegala. The cultivation areas were Jaffna, Anuradhapura, Kurunegala, Nuwara-Eeliya, Kandy, Badulla, Puttalam, Matale, Hambanthota and Moneragala districts. In addition information was gathered from Thambuththegama, Dambulla, Meegoda, Nuwara Eliya, Norochchole economic centres and Colombo Mannin market.



Furthermore, information were collected through interviewing key informants such as officers from Department of Agriculture, Department of Agrarian Development, Sri Lanka Mahaweli Authority, Chairmen of Farmer Organizations and Traders Associations, Managers of Economic centers in these areas and other related personals. Direct observations and secondary sources were also used to collect the information. Data were analyzed by using Minitab statistical package.

2.2 Loss assessment study:

Loss assessment studies were conducted through following major fruits and vegetables supply chains in Sri Lanka that represents the whole country,

- Thambuttegama to Meegoda (Green chili, long bean, papaya, mukunuwenna, bnana)
- Thambuttegama to Veyangoda (Brinjal, okra, tomato, long bean, bitter guard)
- Kalpitiya to Colombo (Long bean, cabbage, okra, capsicum)
- Nuwara-Eliya to Dambulla (Carrot, potato, cabbage)
- Nuwara-Eliya to Colombo (Carrot, capsicum, cabbage, banana)
- Jaffna to Dambulla (Brinjal, papaya, okra)
- Omaragolla to Colombo (Mango)

Commodities were transported in polysack bags as conventional post harvest practice and as improved practices they were transported using plastic crates simultaneously at ambient conditions. The temperature and relative humidity, both in-pack and in-fruit, were measured at the starting point of the journey, during transport, at the end of the journey and at the levels. Mechanical damages and physiological weight loss of selected crops were measured at farmer, transporter/wholesaler and retailer stages of supply chains in both conventional and improved methods. Mechanically damages due to compression; abrasion and vibration and the combined effect were distinguished visually and weights were taken. Percentage of mechanical damages was calculated for different samples using the following equation (Dadzie and Orchard, 1997).

$$MD = \frac{W_2}{W_1} \times 100 \qquad (1)$$

Where MD is the percentage of mechanical damage, W_2 is the damaged fruit weight (kg) and W_1 is the initial sample weight (kg).

Physiological weight loss was determined using weight different among handling stages and presented as percentage values. Postharvest loss included both mechanical damages and physiological weight loss percentages.

III. RESULTS AND DISCUSSIONS

3.1 Present status of postharvest practices:

The fruits and vegetables are sold at farm gate or through the middle man who go to the farm and buy the produce and selling through middle man is widely practiced, as large volume of products are collected by middle man and sells it by bringing to the wholesaler and retailer (Bhattarai, 2018). Therefore, they are playing different roles in agriculture supply chain. Harvesting of produce at correct maturity is an important practice of agriculture. The harvesting time of fruits should be at physiological maturity when they attain maximum dry weight and that of vegetable should be harvested at horticultural maturity or field maturity (Pokhrel, 2021).

Figure 01 presents the adaptation levels of farmers to harvest fruits and vegetables at correct maturity stages in Sri Lanka. Harvesting of agriculture commodities at correct maturity is an important practice to reduce the postharvest loss. As depicted by the study, most of farmers well aware about maturity indices of fruits and vegetables, and majority of them consider correct maturity when crops are harvested. All the papaya farmers (100%) participated to the survey consider correct maturity for harvesting. Among farmers, 5-31 % of farmers do not consider maturity indices during the harvesting of selected crops. According to their respond, market demand, availability of transport vehicles, price fluctuations, labour availability and weather conditions are considered for harvesting rather than maturity. Fernando, (2006) stated that the majority of vegetables have previously been harvested at incorrect mature stages resulting significant post harvest losses. In addition, the small scale farmers generally do not have adequate facilities to sort and grade their produce. But, commercial level farms have these facilities and sorting is practiced at the farm to remove the malformed, diseased and mechanically damaged commodities. Njuguna, *et al.* (2001) also previously have revealed similar situations.

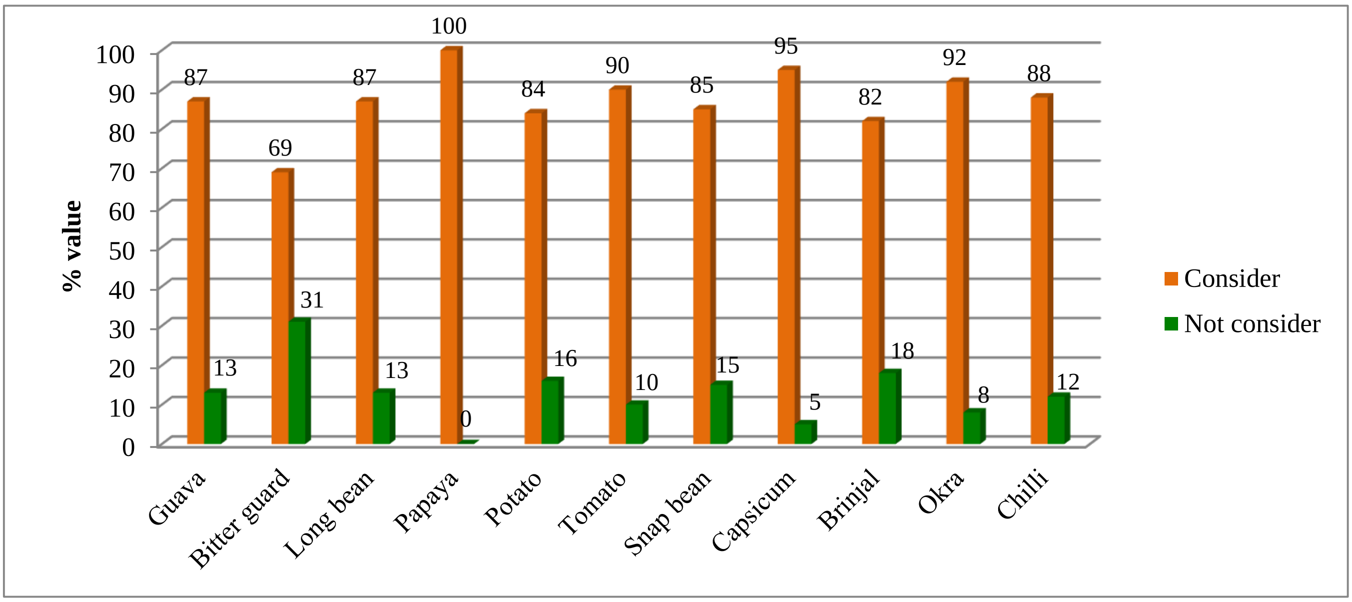


FIGURE 1: Adapting for correct maturity at harvesting

3.1.1 Mode of transport used for different crops:

A major part of the losses occurs during transportation from former to retail outlets through collector, wholesale markets and transport agents (Fernando, 2006; Kitinoja *et al*. 2012). Figure 02 exhibits the different types of vehicles used for transporting fruits and vegetables in Sri Lanka. The majority of stakeholders in perishables supply chains in Sri Lanka, transport fruits and vegetables using different types vehicles. These can be mainly categorized in to four groups: open trucks, close trucks, refrigerated trucks and other means of transportation. Small slow-running vehicles such as three wheelers and two - and four-wheel tractors are considered in the “others” category. The close truck category is dominant in transporting majority of commodities while guava, bitter guar, long bean and potato are transported in open trucks. Only snap bean and capsicum were found transported in refrigerated trucks. It is also around 3%. Open trucks do not have covers to protect (especially from sunburn, rain) fruits and vegetables during transport. Hence, lack of proper transportation modes and method of transportation apparently result low quality of produce received to retail markets and consequently to final consumer and high wastage. Vidanapathirana *et al*. (2018) has earlier mentioned that of transportation method is one of the major main factors affecting quality of commodities, especially for most perishable produce.

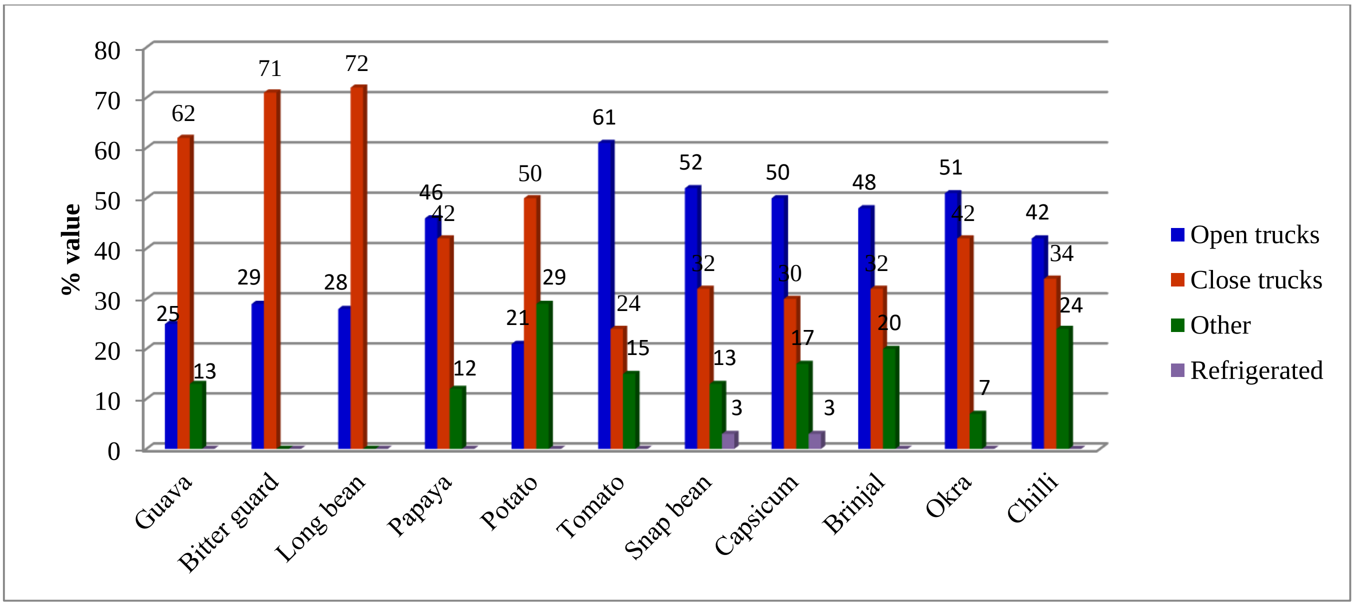


FIGURE 2: Different types vehicles used for transport fruits and vegetables

3.1.2 Use of different packaging methods for fruits and vegetables:

Use of proper packaging methods is considered as one of the important aspects for post harvest loss reduction in fruits and vegetables. It protects commodities from mechanical injuries, tampering, and contamination from physical, chemical, and biological sources which also enables (Arah *et al*. 2016). Figure 03 illustrates the use of different packaging method for fruit and vegetables during the handling transportation in Sri Lanka. As the study reveals, fruits and vegetables are packed four types packaging methods during post harvest handling; polysack bags (PS), plastic crates (PC), wooden boxes (WB) and corrugated fibreboard boxes (CFB). As indicated by Pokhrel, (2021), for varies fruits and vegetables, different packaging materials methods of like corrugated cardboard boxes, various sizes of plastic trays, nylon sacks, wooden crates, polythene bags are used mostly in developing countries to minimize post-harvest loss. According to the results, most of vegetables are still transported in polysack bags (76% in average). Majority of polysack bags are mesh type while woven polysack bags are used to transport okra. 94 % of papaya is usually transported in plastic crates while 54 % of guava is also transported using plastic crates and corrugated fiberboard boxes. Further, majority of tomatoes (83%) are packed in wooden boxes which are not scientifically manufactured packaging type that leads to certain amount of damages. This is a certain level of satisfactory condition compared to previous situation. According to Dharmasena and Sarananda (2012), 97 %of the fruits and vegetables in Sri Lanka were handled through the conventional distribution chains in which agricultural produce is channeled through economic centres with the involvement of middlemen using improper handling practices. Chhetri *et al.* (2023) also mentioned that a large portion of stakeholders of agriculture supply chain still depend on traditional methods of packaging though newer technologies and methods are implemented for fruits and vegetable to minimize post-harvest loss.

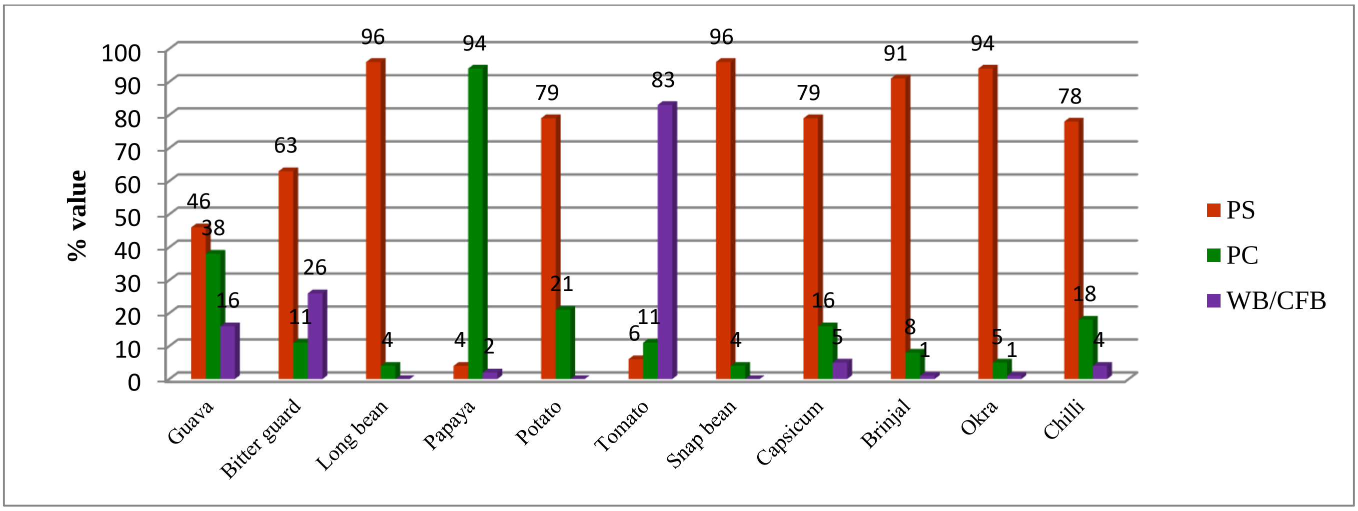


FIGURE 3: Use of different packaging materials for perishables

Use of different packaging methods by different stakeholders of vegetables supply chain is indicated by figure 04. There are several players involved in fulfilling the needs of the consumer in the supply chain management of fruits and vegetables such as farmers, local traders, transporters, processors and retailers (Vidanapathirana, *et al*.2018). As depicted by figure 04, majority of farmers, collectors, wholesalers, transporters and retailers (79-91%) use polysack bags for packing vegetables during handling and transportation. 5-12 % of them used to handle vegetables in plastic crates while 4 -11% of stakeholders in vegetables supply chain use wooden boxes and corrugated fibre board boxes. In addition, collectors and wholesalers have adapted to use other types of packaging methods for vegetables such as polyethylene, wooden compartments in transport vehicles, paper wrappings.

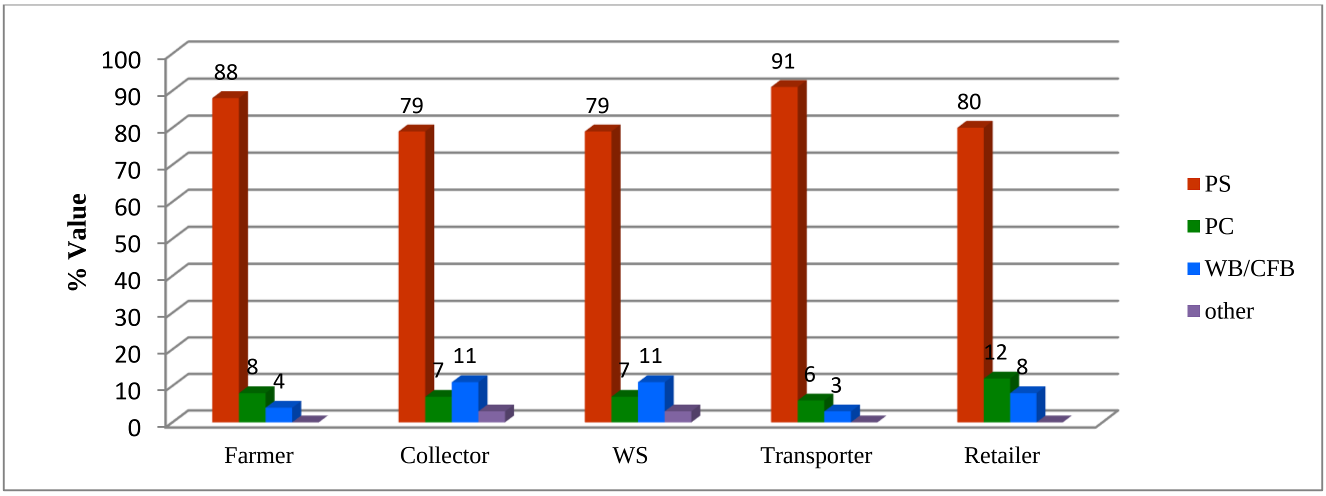


FIGURE 4: Different packaging methods used for vegetables by different stakeholders

3.1.3 Use of packaging methods by different stakeholders of fruit supply chain:

As shown by figure 05, all the stakeholders in fruit supply chain mainly use plastic crates (46 – 53%) for handling and transportation of fruits resulting low postharvest losses of fruits. The second most packaging methods used for fruits are wooden boxes and corrugated fibre board boxes (26-33%). 16 – 23 % of stakeholders still use polysack bags for packing fruits. According to the results of the survey, majority of stakeholders in Sri Lankan fruit supply chain have adopted to practice correct post harvest handling methods so that fruit quality could be preserved and better market price could be obtained. Vidanapathirana *et al.* (2018), also have revealed that unlike for vegetables, safe packages are used for packing and transporting fruits such as mango, papaya and guava in conventional supply chains. Mostly used safe packages were plastic crates, corrugated fiberboard boxes and wooden boxes.

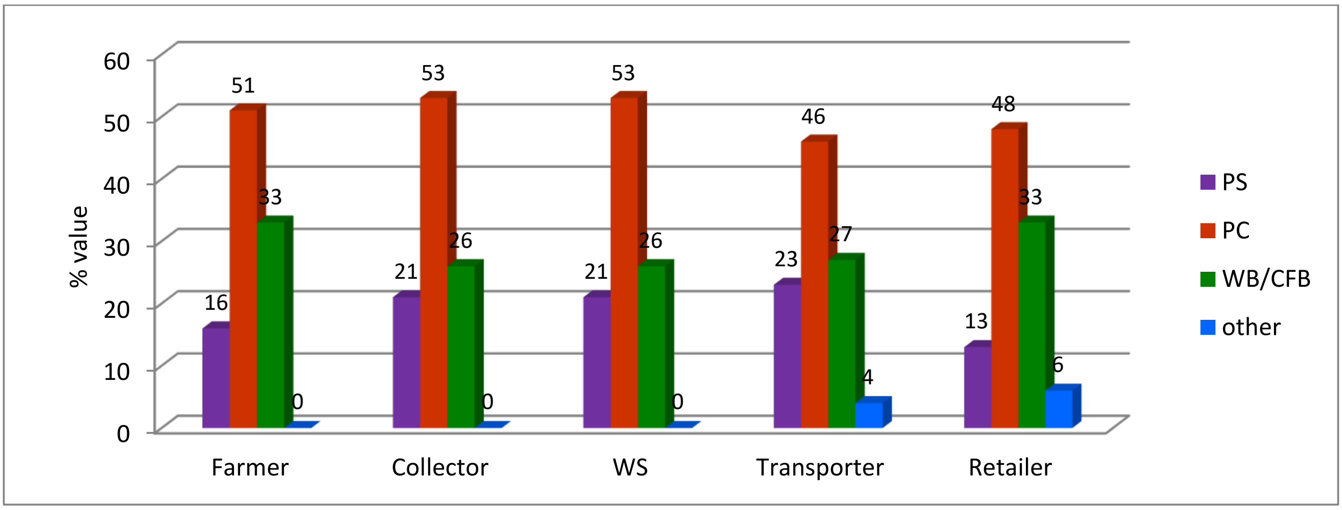


FIGURE 5: Different packaging methods used for fruits by different stakeholders

3.2 Postharvest losses:

The term "post-harvest losses" in the PHL system refers to the quantitative and qualitative loss of food in various post-harvest operations (Abass *et al*. 2014). Fresh fruits and vegetables are highly susceptible to mechanical injury due to soft texture and high moisture content. Poor handling and improper packaging methods for transportation are the causes of bruising, cutting, breaking, impact wounding and other forms of injury in fresh fruits and vegetables.

3.2.1 Quantitative post harvest losses of fruits and vegetables:

As indicated by table 01and 02, previous loss assessment studies conducted in Sri Lanka have revealed that post harvest loss of fruits and vegetables were 30 – 40%. Cabbage exhibited the highest loss among vegetables while bitter guard showed the least value. According to loss assessment study, the present post harvest losses of vegetables in conventional supply chain is 12.46± 0.59 - 28.24 ± 0.41% while it is in improved value chain where correct postharvest handling methods are used is 5.01±

0.30 - 9.46± 1.03%. The main factors that are most consistently related to higher levels of postharvest losses include rough handling, use of poor quality packages, high postharvest handling temperatures and delays in marketing (Kitinoja and Hassan 2012; Kitinoja and Cantwell 2010; Molla *et al.* 2010). However, the present study exhibited that the prevailed postharvest losses of fruits and vegetables in Sri Lanka have reduced from 30 - 40% to 12 - 28 %. Further, the study clearly showed that the post harvest loses of fruits have reduced remarkably recently from 30 – 46 % to 20 % even in conventional fruit supply chain. Improved value chain showed 6 – 19 % value. Similar results have previously reported by Herath *et al.* (2021) and Wasala *et al.* (2014). As previously reported by Dissanayake *et al*. (2020) and Vidanapathirana *et al.* (2018), Several programs have been conducted during last two decades to minimize postharvest losses, with special emphasis on the improvement of supply and value chains of fruits and vegetables by conducting awareness creation program, introducing safe packages, introducing correct ripening methods, introducing pack-house operations and development of entrepreneurship via applying value added technologies to surplus production. Further, supermarkets and other upgraded markets, who handle 5% of the total production, have developed their supply chains by applying correct postharvest technologies; as a result, postharvest loss of their produce has decreased to nearly 5%.

TABLE 1
AVERAGE QUANTITATIVE POST HARVEST LOSSES OF VEGETABLES

Vegetable crop	Postharvest Loss (% weight)-previous	Postharvest loss (% weight) year 2023	Postharvest loss in improved value chains (% weight)
Snap Bean	40	23.84 ± 0.12	6.32 ± 0.19
Okra	40	28.24 ± 0.41	7.17 ± 0.26
Brinjal	30	20.31 ± 3.11	7.45 ± 1.22
Cabbage	43	20.43 ± 0.55	7.91 ± 0.61
Carrot	30	22.46± 0.65	6.51± 0.24
Capsicum	30-40	25.74± 0.95	8.29± 0.62
Long Bean	40	20.36± 2.16	9.38± 1.07
Potato	-	14.46± 0.28	5.01± 0.30
Mukunuwenna	-	12.46± 0.59	6.84± 0.35
Green chilli	30-40	19.62± 1.04	4.97± 0.23
Bitter gourd	25	24.71± 2.25	9.46± 1.03
Tomato	29	15.93± .84	7.31± 0.71

(Sarananda, 2005; Vidanapathirana,et al., 2018; Wasala et al., 2012; Gunawardhana et al., 2014)

TABLE 2
AVERAGE QUANTITATIVE POST HARVEST LOSSES OF FRUITS

Fruit crop	Postharvest Loss (% weight)-previous	Postharvest Loss (% weight) year 2023	Postharvest Loss in improved value chains (% weight)
Papaya	46	19.58 ± 2.13	11.40 ± 0.72
Guava	30-40	20.37 ± 0.98	6.47 ± 0.81
Banana	30-35	26.54 ± 3.04	18.65 ± 1.31
Mango	41	15.15 ± 1.03	5.96 ± 0.26

(Sarananda, 2005; Karunagoda et al. 2011)

IV. CONCLUSION

As depicted by the results and compared previous studies, the adaptation to the use of postharvest technologies by stakeholders for fruits and vegetables in Sri Lanka was comparatively higher at different operational stages. Majority of farmers are aware of correct maturity indices and they already have adapted to use them. Findings further exhibited that use of safe packaging materials for transportation of fruits has significantly expanded. However, introduction of safe packaging for vegetables should be further required. Postharvest loss of fruits in Sri Lanka at present is around 15-20% while it is 20-30% in vegetables saving considerable volume of commodities after harvesting.

REFERENCES

[1] Abass A.B., Ndunguru, G., Mamiro, P., Alenkhe, B, Mlingi N. and Bekunda, M. (2014)Post-harvest food losses in a maize based farming system of semi-arid savannah area of Tanzania. Journal of Stored Product Research, 57:49–57. https://doi.org/ 10.1016/j.jspr.2013.12.004

[2] Arah, I.K., Ahorbo, G.K., Anku, E.K., Kumah, E.K., and Amaglo, H. (2016). Postharvest handling practices and treatment methods for tomato handlers in developing countries: A mini review. Advances in Agriculture, Pp. 1–8. https://doi.org/10.1155/2016/6436945

[3] Bhattarai, D.R., (2018). Postharvest horticulture in Nepal. Horticulture International Journal, https://doi.org/10.15406/hij.2018.02.00096 2 (6).

[4] Buzby, C. and Hyman, J. (2012). Total and per capita value of food loss in the United States, Food Policy, 37 (5): 561-570. https://doi.org/10.1016/j.foodpol.2012.06.002.

[5] Chhetri, R. T., Magar, P., Kandel, S. and Gnyawali P. (2023). A review paper on post-harvest loss on fruits and vegetables, Food and Agri Economics Review, 3(1): 01-04.

[6] Dadzie, B.K. and Orchard, J.E. (1997). Routing postharvest screening of banana/plantain hybrids: Criteria and methods. INIBAP technical guidelines No. 2. INIBAP, Montpelier.

[7] Dharmasena, D.A.N. and Sarananda, K.H. (2012). Present status, issues, and future trends in fruit and vegetable handling, distribution and marketing in Sri Lanka. Workshop on postharvest technology and cold chain management. 20-22 March 2012, Amity International Centre for Postharvest Technology and Cold Chain Management, Noida, India. Available at http://www.fruits.soton.ac.uk/?page_id=111.

[8] Dharmathilake, N.R.D.S., Rosairo, H.S.R., Ayoni, V.D.N. and Herath. R.M. (2020). Implications of post-harvest losses and acreage response of selected up-country vegetables from Nuwaraeliya district in Sri Lanka on sustained food security The Journal of Agricultural Sciences - Sri Lanka, 15(1):88-100. http://doi.org/10.4038/jas.v15i1.8674.

[9] Dissanayake, C.A.K., Wasala, W.M.C.B., Gunawardhane, C.R., Wijewardhane, R.M.N.A.and Herath, M.M. (2020). Introduction of plastic crates to vegetable wholesalers in major economic centers in Sri Lanka: why do people refuse it? In IV International Conference on Postharvest and Quality Management of Horticultural Products of Interest for Tropical Region, 1278(23):151–156.

[10] Fernando, M.D. (2006). Country paper: Sri Lanka (2). In: APO. 2006. Postharvest Management of Fruit and Vegetables in the Asia-Pacific Region. Asian Productivity Organization (APO) and FAO. 264-275.

[11] Gunawardhane, C.R., Wasala, W.M.C.B., Dissanayake, C.A.K., Wijewardene, R.M.N.A., Chandrajith, U.G. and Thilakaratne, B.M.K.S. (2014). Use of safe packaging for vegetable transportation on main supply chains in Sri Lanka, Proc. of the international research symposium on postharvest technology held in Anuradhapura, Sri Lanka on 19th, June 2014

[12] Herath, M. M., Dissanayake, C. A. K., Wasala, W. M. C. B., Somakanthan, N. and Gunawardhane, C. R. (2021). The effect of improved postharvest practices on the postharvest losses and quality of mango fruit in Sri Lanka's supply chain. *Journal of Horticulture and Postharvest Research, 4*(Issue 4), 509-520. doi: 10.22077/jhpr.2021.4442.1222

[13] Iordachescu, G., Ploscuțanu, G., Pricop, E. M., Baston, O. and Barna, O. (2019). Postharvest losses in transportation and storage for fresh fruits and vegetables sector, Journal of International Scientific Publications, 7:244-251.

[14] Kitinoja, L. and Al Hassan, H. A. (2012). Identification of appropriate postharvest technologies for improving market access and incomes for small horticultural farmers in Sub-Saharan Africa and South Asia. Part 1: Postharvest Losses and Quality Assessments. Acta Hort (IHC 2010) 934: 31-40.

[15] Molla, M. M., Islam, M. N., Nasrin T. A. A. and Bhuyan, M. A. J. (2010). Survey on postharvest practices and losses of litchi in selected areas of Bangladesh. Bangladesh Journal of Agricultural Research, 35 (3): 439-451.

[16] Njuguna, L., Kibaki, J., Muchui,M., . Kambo, C. M., Munene, S. and Wepukhulu, S. B. (2001). Snow pea and sugar snap production in mt. Kenya region: status, challenges, and opportunities. Proceedings of the Horticulture seminar on Sustainable Horticultural Production in the tropics Oct. 3rd to 6th 2001. Jomo Kenyatta University of Agriculture and Technology, JKUAT, Juja, Kenya.

[17] Pokhrel, B. (2021). Review on post-harvest handling to reduce loss of fruits and vegetables. http://www.hortijournal.com

[18] Rajapaksha, L., Gunathilake, D.M.C.C., Pathirana, S.M. and Fernando, T.N. (2021). Reducing post-harvest losses in fruits and vegetables for ensuring food security – Case of Sri Lanka. MOJ Food Process Technology, 9(1):7–16. DOI: 10.15406/mojfpt.2021.09.00255

[19] Vidanapathirana, R., Champika, J., Rambukwella, R. Wijesooriya, N. (2018). Quality and safety issues in fruit and vegetable supply chains in Sri Lanka: A Review. Hector Kobbekaduwa Agrarian Research and Training Institute, 2018; 120.

[20] Wasala, W.M.C.B., Dissanayake, C.A.K., Dharmasena, D.A.N., Gunawardane, C.R. and Dissanayake, T.M.R. (2014). Postharvest losses, current issues and demand for postharvest technologies for loss management in the main banana supply chains in Sri Lanka, Journal of Postharvest Technology, 2(01) : 80-87.

[21] Karunagoda, K., Rajapakse, R.D.D.P., Ayoni, V.D.N. and Rambukpitiya, S.D. (2011) “Post-harvest Losses of Up-country Vegetables in Sri Lanka”. Annals of the Sri Lanka Department in Agriculture, Research News, 13.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