NAAS RATING: 4.23

# AGRICULTURE JOURNAL IJOEAR

# VOLUME-11, ISSUE-10, OCTOBER 2025

DOWNLOAD NOW

Contact us +91-7665235235 www.ijoear.com info@ijoear.com

# Preface

We would like to present, with great pleasure, the inaugural volume-11, Issue-10, October 2025, of a scholarly journal, *International Journal of Environmental & Agriculture Research*. This journal is part of the AD Publications series *in the field of Environmental & Agriculture Research Development*, and is devoted to the gamut of Environmental & Agriculture issues, from theoretical aspects to application-dependent studies and the validation of emerging technologies.

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

**Environmental Research:**

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

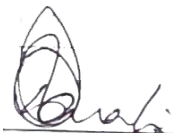
**Agriculture Research:**

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

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

Mukesh Arora

(Managing Editor)



Dr. Bhagawan Bharali

(Chief Editor)

# Fields of Interests

| Agricultural Sciences | |
|---|---|
| Soil Science | Plant Science |
| Animal Science | Agricultural Economics |
| Agricultural Chemistry | Basic biology concepts |
| Sustainable Natural Resource Utilisation | Management of the Environment |
| Agricultural Management Practices | Agricultural Technology |
| Natural Resources | Basic Horticulture |
| Food System | Irrigation and water management |
| **Crop Production** | |
| Cereals or Basic Grains: Oats, Wheat, Barley, Rye, Triticale, Corn, Sorghum, Millet, Quinoa and Amaranth | Oilseeds: Canola, Rapeseed, Flax, Sunflowers, Corn and Hempseed |
| Pulse Crops: Peas (all types), field beans, faba beans, lentils, soybeans, peanuts and chickpeas. | Hay and Silage (Forage crop) Production |
| Vegetable crops or Olericulture: Crops utilized fresh or whole (wholefood crop, no or limited processing, i.e., fresh cut salad); (Lettuce, Cabbage, Carrots, Potatoes, Tomatoes, Herbs, etc.) | Tree Fruit crops: apples, oranges, stone fruit (i.e., peaches, plums, cherries) |
| Tree Nut crops: Hazlenuts. walnuts, almonds, cashews, pecans | Berry crops: strawberries, blueberries, raspberries |
| Sugar crops: sugarcane. sugar beets, sorghum | Potatoes varieties and production. |
| **Livestock Production** | |
| Animal husbandry | Ranch |
| Camel | Yak |
| Pigs | Sheep |
| Goats | Poultry |
| Bees | Dogs |
| Exotic species | Chicken Growth |
| **Aquaculture** | |
| Fish farm | Shrimp farm |
| Freshwater prawn farm | Integrated Multi-Trophic Aquaculture |

| Milk Production (Dairy) | |
|---|---|
| Dairy goat | Dairy cow |
| Dairy Sheep | Water Buffalo |
| Moose milk | Dairy product |
| **Forest Products and Forest management** | |
| Forestry/Silviculture | Agroforestry |
| Silvopasture | Christmas tree cultivation |
| Maple syrup | Forestry Growth |
| **Mechanical** | |
| General Farm Machinery | Tillage equipment |
| Harvesting equipment | Processing equipment |
| Hay & Silage/Forage equipment | Milking equipment |
| Hand tools & activities | Stock handling & control equipment |
| Agricultural buildings | Storage |
| **Agricultural Input Products** | |
| Crop Protection Chemicals | Feed supplements |
| Chemical based (inorganic) fertilizers | Organic fertilizers |
| **Environmental Science** | |
| 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 |
| Theoretical production ecology | horticulture |
| Breeding | plant fertilization |

# Board Members


## Dr. Bhagawan Bharali (Chief Editor)

Professor & Head, Department of Crop Physiology, Faculty of Agriculture, Assam Agricultural University, Jorhat-785013 (Assam).

## Mr. Mukesh Arora (Managing Editor)

M.Tech (Digital Communication), BE (Electronics & Communication), currently serving as Associate Professor in the Department of EE, BIET, Sikar.

## Dr. Kusum Gaur (Associate Editor)

Dr. Kusum Gaur working as professor Community Medicine and member of Research Review Board of Sawai Man Singh Medical College, Jaipur (Raj) India.

She has awarded with WHO Fellowship for IEC at Bangkok. She has done management course from NIHFW. She has published and present many research paper in India as well as abroad in the field of community medicine and medical education. She has developed Socio-economic Status Scale (Gaur's SES) and Spiritual Health Assessment Scale (SHAS). She is 1st author of a book entitled " Community Medicine: Practical Guide and Logbook.

**Research Area:** Community Medicine, Biostatics, Epidemiology, Health and Hospital Management and Spiritual Health

## Dr. Darwin H. Pangaribuan

Associate Professor in Department of Agronomy and Horticulture, Faculty of Agriculture, University of Lampung, Indonesia.

**Educational background:** (Ir.) from Faculty of Agriculture, IPB University, Bogor, Indonesia; (Dipl. Eng) in Land Evaluation from the University of Tweente (UT-ITC), Enschede, The Netherlands; (M.Sc) in Crop Production from Wageningen University (WU), The Netherlands. (Ph.D) in Horticulture from University of Queensland (UQ), Brisbane, Australia.

**Research Interest:** Vegetable Production & Physiology; Biostimulant & Biofertilizers; Organic Farming, Multiple Cropping, Crop Nutrition, Horticulture.

## Dr Peni Kistijani Samsuria Mutalib

Working as Research coordinator and HOD in the department of Medical Physics in University of Indonesia.

## Dr. Govindaraj Kamalam Dinesh, PhD

Department of Biochemistry, Physiology, Microbiology and Environmental Science College of Agriculture, Iroisemba

Central Agricultural University, Imphal, Manipur – 795004, India

**Specialization:** Ecosystem services, Conservation agriculture, Climate change, Agroecology, Greenhouse gas emissions from agriculture, Agricultural ornithology, Carbon sequestration

**Academic Qualifications:** B.Sc. (Agriculture), Annamalai University, M.Sc. (Environmental Science), Tamil Nadu Agricultural University (TNAU), Ph.D. (Environmental Sciences), ICAR-IARI, New Delhi (UGC-JRF, IARI PhD SRF, All India Rank – 5)

## Professor Jacinta A.Opara

Working full-time and full-ranked Professor and Director, Centre for Health and Environmental Studies at one of the top 10 leading public Universities in Nigeria, the University of Maiduguri-Nigeria founded in 1975.

## Dr. Samir B. Salman AL-Badri

Samir Albadri currently works at the University of Baghdad / Department of Agricultural Machines and Equipment. After graduation from the Department of Plant, Soils, and Agricultural Systems, Southern Illinois University Carbondale. The project was 'Hybrid cooling to extend the saleable shelf life of some fruits and vegetables. I worked in many other subject such as Evaporative pad cooling.

**Orchid ID:** https://orcid.org/0000-0001-9784-7424

**Publon Profile:** https://publons.com/researcher/1857228/samir-b-albadri

## Dr. Goswami Tridib Kumar

Presently working as a Professor in IIT Kharagpur from year 2007, He Received PhD degree from IIT Kharagpur in the year of 1987.

## Prof. Khalil Cherifi

Professor in Department of Biology at Faculty of Sciences, Agadir, Morocco.

## Dr. Josiah Chidiebere Okonkwo

PhD Animal Science/ Biotech (DELSU), PGD Biotechnology (Hebrew University of Jerusalem Senior Lecturer, Department of Animal Science and Technology, Faculty of Agriculture, Nau, AWKA.

## Dr. Jadala Shankaraswamy

**Specialization:** Horticulture, Post-Harvest Technology, Phytochemistry, Nanobiotechnology, 3D Food Printing

**Academic Qualifications:** B.Sc. (Horticulture), M.Sc. (Post-Harvest Technology of Horticultural Crops), Ph.D. (Horticulture)

Assistant Professor (Senior Scale - IX), College of Horticulture, Mojerla, Sri Konda Laxman Telangana State Horticultural University, Telangana, India

Dr. Jadala Shankaraswamy is an Assistant Professor (Senior Scale – IX) at Sri Konda Laxman Telangana State Horticultural University, Telangana, India. His research focuses on post-harvest technology, phytochemistry, nanobiotechnology, and value addition in horticultural crops. He has contributed to innovative product development, holds patents in horticultural science, and has received several national and international awards for his research excellence.

## Dr. Tarun Kumar Maheshwari

Dr. Tarun Kumar Maheshwari, Head of Agricultural Engineering at Dr. BRA College of Agricultural Engineering and Technology, Etawah, specializes in farm machinery and power engineering. He holds a Ph.D. from Sam Higginbottom University and an M.Tech. from IIT Kharagpur.

## Prof. Özhan ŞİMŞEK

Agriculture Faculty, Department of Horticulture, Çukurova University, Adana, 01330 Turkey.

## Dr. Anka Ozana Čavlović

Working as Professor in the department of Faculty of Forestry, University of Zagreb, Svetošimunska 25, Zagreb.

## Dr. Rakesh Singh

Professor in Department of Agricultural Economics, Institute of Agricultural Sciences, Banaras Hindu University, Also Vice President of Indian Society of Agricultural Economics, Mumbai.

## Dr. Sunil Wimalawansa

MD, PhD, MBA, DSc, is a former university professor, Professor of Medicine, Chief of Endocrinology, Metabolism & Nutrition, expert in endocrinology; osteoporosis and metabolic bone disease, vitamin D, and nutrition.

## Dr. Smruti Sohani

Dr. Smruti Sohani, has Fellowship in Pharmacy & Life Science (FPLS) and Life member of International Journal of Biological science indexed by UGC and e IRC Scientific and Technical Committee. Achieved young women scientist award by MPCOST. Published many Indian & UK patents, copyrights, many research and review papers, books and book chapters. She Invited as plenary talks at conferences and seminars national level, and as a Session chair on many International Conference organize by Kryvyi Rih National University, Ukraine Europe. Designated as state Madhya Pradesh Coordinator in International conference collaborated by RCS. Coordinator of two Professional Student Chapter in collaboration with Agriculture Development society and research Culture Society. her enthusiastic participation in research and academia. She is participating on several advisory panels, scientific societies, and governmental committees. Participant in several worldwide professional research associations; member of esteemed, peer-reviewed publications' editorial boards and review panels. Many Ph.D., PG, and UG students have benefited from her guidance, and these supervisions continue.

## Dr. Ajeet singh Nain

Working as Professor in GBPUA&T, Pantnagar-263145, US Nagar, UK, India.

## Dr. Salvinder Singh

Presently working as Associate Professor in the Department of Agricultural Biotechnology in Assam Agricultural University, Jorhat, Assam.

Dr. Salvinder received MacKnight Foundation Fellowship for pre-doc training at WSU, USA – January 2000-March 2002 and DBT overseas Associateship for Post-Doc at WSU, USA – April, 2012 to October, 2012.

## Dr. V K Joshi

Professor V.K.Joshi is M.Sc., Ph.D. (Microbiology) from Punjab Agricultural University, Ludhiana and Guru Nanak Dev University, Amritsar, respectively with more than 35 years experience in Fruit Fermentation Technology, Indigenous fermented foods, patulin ,biocolour ,Quality Control and Waste Utilization. Presently, heading the dept. of Food Science and Technology in University of Horticulture and Forestry, Nauni-Solan (HP), India.

## Dr. Mahendra Singh Pal

Presently working as Professor in the dept. of Agronomy in G. B. Pant University o Agriculture & Technology, Pantnagar-263145 (Uttarakhand).

## Dr. Sanjoy Kumar Bordolui

M.Sc. (Ag.), PhD, FSTA, FSIESRP, Assistant Professor, Department of Seed Science and Technology, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, Nadia. W.B., India. He received CWSS Young Scientist Award-2016, conferred by Crop and Weed Science Society, received Best Young Faculty Award 2019 conferred by Novel Research Academy, received Innovative Research & Dedicated Teaching Professional Award 2020 conferred by Society of Innovative Educationalist & Scientific Research Professional, Chennai.

## Dr.Chiti Agarwal

Dr. Chiti Agarwal works as a postdoctoral associate at the University of Maryland in College Park, Maryland, USA. Her research focuses on fungicide resistance to fungal diseases that affect small fruits such as strawberries. She graduated from North Dakota State University in Fargo, North Dakota, with a B.S. in biotechnology and an M.S. in plant sciences. Dr. Agarwal completed her doctorate in Plant Pathology while working as a research and teaching assistant. During her time as a graduate research assistant, she learned about plant breeding, molecular genetics, quantitative trait locus mapping, genome-wide association analysis, and marker-assisted selection. She wants to engage with researchers from many fields and have a beneficial impact on a larger audience.

## DR. Owais Yousuf

Presently working as Assistant professor in the Department of Bioengineering, Integral University-Lucknow, Uttar Pradesh, India.

## Dr. Vijay A. Patil

Working as Assistant Research Scientist in Main Rice Research Centre, Navsari Agricultural University, Navsari. Gujarat- 396 450 (India).

## Dr. Amit Kumar Maurya

Working asJunior Research Assistantin the Department of Plant Pathology at Sam Higginbottom University of Agriculture, Technology and Sciences, Prayagraj, U.P. India.

## Prof. Salil Kumar Tewari

Presently working as Professor in College of Agriculture and Joint Director, Agroforestry Research Centre (AFRC) / Program Coordinator in G.B. Pant University of Agric. & Tech., Pantnagar - 263 145, Uttarakhand (INDIA).

## Dr. S. K. Jain

Presently working as Officer Incharge of All India Coordinated Sorghum Improvement Project, S. D. Agricultural University, Deesa, Gujarat.

## Dr. Deshmukh Amol Jagannath

Presently working as Assistant Professor in Dept. of Plant Pathology, College of Agriculture polytechnic, NAU, Waghai.

## Mr. Anil Kumar

Working as Junior Research Officer/Asstt. Prof. in the dept. of Food Science & Technology in Agriculture & Technology, Pantnagar.

## Mr. Jiban Shrestha

**Scientist (Plant Breeding & Genetics)**

Presently working as Scientist (Plant Breeding and Genetics) at National Maize Research Programme (NMRP), Rampur, Chitwan under Nepal Agricultural Research Council (NARC), Singhdarbar Plaza, Kathmandu, Nepal.

## Mr. Aklilu Bajigo Madalcho

Working at Jigjiga University, Ethiopia, as lecturer and researcher at the College of Dry land Agriculture, department of Natural Resources Management.

## Mr. Isaac Newton ATIVOR

MPhil. in Entomology, from University of Ghana.

He has extensive knowledge in tree fruit orchard pest management to evaluate insecticides and other control strategies such as use of pheromone traps and biological control to manage insect pests of horticultural crops. He has knowledge in agronomy, plant pathology and other areas in Agriculture which I can use to support any research from production to marketing.

## Mr. Bimal Bahadur Kunwar

He received his Master Degree in Botany from Central Department of Botany, T.U., Kirtipur, Nepal. Currently working as consultant to prepare CCA-DRR Plan for Hariyo Ban Program/CARE in Nepal/GONESA.

# Table of Contents

## Volume-11, Issue-10, October 2025


| S.No | Title | Page No. |
|---|---|---|
| 1 | **Climate Change and Sustainable Development in Africa: Assessing the Rising Threat to Socioeconomic Progress**<br>**Authors:** Douglas Ncube; Rudo Abigail Togaraseyi<br>**DOI:** https://dx.doi.org/10.5281/zenodo.17489784<br>**Digital Identification Number:** IJOEAR-OCT-2025-1 | **01-14** |
| 2 | **Nano Bionic Effect of Multiwall Carbon Nanotubes (MWCNT) and Graphene Oxides (GO) for Climate Resilient Horticultural Plants: A Strategy for Ensuring Food Security**<br>**Authors:** Jadala Shankaraswamy<br>**DOI:** https://dx.doi.org/10.5281/zenodo.17489797<br>**Digital Identification Number:** IJOEAR-OCT-2025-2 | **15-20** |
| 3 | **Coffee and Tribal Communities in Wayanad: Historical, Socio-Economic, and Environmental Dimensions**<br>**Authors:** Krishna Chandana<br>**DOI:** https://dx.doi.org/10.5281/zenodo.17489808<br>**Digital Identification Number:** IJOEAR-OCT-2025-3 | **21-29** |
| 4 | **Development and Evaluation of Vegetable and Fish Wastes Silage (VFWS) Additive to Nile Tilapia (*Oreochromis niloticus*) Feeds**<br>**Authors:** Fenny A. Alleluya; Antonio J. Barroga; Luzviminda S. Quitos; Criselda P. Francisco; Redel L. Gutierrez<br>**DOI:** https://dx.doi.org/10.5281/zenodo.17489820<br>**Digital Identification Number:** IJOEAR-OCT-2025-4 | **30-43** |
| 5 | **Traditional Medicine Practices in Tribal Communities of Wayanad, Kerala: Ethnobotanical Insights and Conservation Challenges for Endangered Species**<br>**Authors:** Mr. Sabu V.U.; Dr. Jithesh M. P.<br>**DOI:** https://dx.doi.org/10.5281/zenodo.17489831<br>**Digital Identification Number:** IJOEAR-OCT-2025-5 | **44-50** |
| 6 | **Status of Zinc Content in Soils and Rice Genotypes and its Relationship with Soil Chemical Properties across different Agro-Climatic Zones of Karnataka, South India**<br>**Authors:** Chakpram Birendrajit; Prakash Nagabovanalli<br>**DOI:** https://dx.doi.org/10.5281/zenodo.17489847<br>**Digital Identification Number:** IJOEAR-OCT-2025-8 | **51-67** |

| | | |
|---|---|---|
| **7** | **Evaluation of the Production Efficiency and Profitability of Groundnut Production in Bwari and Gwagwalada Area Councils of Abuja, Nigeria**<br>**Authors:** Funso Omolayo Alabuja; Hauwa Bako; Beatrice Itoya Oyediji; Joseph Bamidele; Sennuga, S. O.<br>**DOI:** https://dx.doi.org/10.5281/zenodo.17489863/<br>**Digital Identification Number:** IJOEAR-OCT-2025-9 | **68-79** |
| **8** | **Entrepreneurship Skill Development in Quality Seed Production of Black Gram (*Vigna mungo*) cv. VBN 8**<br>**Authors:** K. Selvarani; Sayooj M<br>**DOI:** https://dx.doi.org/10.5281/zenodo.17489878<br>**Digital Identification Number:** IJOEAR-OCT-2025-12 | **80-84** |
| **9** | **Geographical Mapping of Liver Fluke (*Fasciola hepatica*) Prevalence through Snail Sampling in Mayantoc, Tarlac**<br>**Authors:** Nestor J. Padilla, Jr.; Rosalie R. Rodrigo; Neil Remoh P. Cano; Arjoe Apolinario; Julius Ceasar Marcelo<br>**DOI:** https://dx.doi.org/10.5281/zenodo.17489890<br>**Digital Identification Number:** IJOEAR-OCT-2025-21 | **85-95** |
| **10** | **Economics of Rice Production and its Effect on Household Food Security Status in Abaji Area Council of Abuja, Nigeria**<br>**Authors:** Mudashir Adeola Olaitan; Beatrice Itoya Oyediji; Joseph Bamidele; Funso Omolayo Alabuja; Sennuga, S. O.<br>**DOI:** https://dx.doi.org/10.5281/zenodo.17489897<br>**Digital Identification Number:** IJOEAR-OCT-2025-25 | **96-109** |
| **11** | **Comparative Quality of Broiler Manure based Compost with or without Compost Additive and its Effect on the Germination of Pechay**<br>**Authors:** Maanne Ayessa M.Tamayo; Antonio J. Barroga; Lea S. Caguiat; Justin V. Dumale; Redel L. Gutierrez<br>**DOI:** https://dx.doi.org/10.5281/zenodo.17489906<br>**Digital Identification Number:** IJOEAR-OCT-2025-28 | **110-124** |
| **12** | **Survey-Based Assessment of Government Schemes' Impact on Rural Infrastructure and Quality of Life in Gajgola Nanak Bari, Moradabad, Uttar Pradesh**<br>**Authors:** Ganesh Datt Bhatt; Mahesh Singh; Parveen Kumar Jain; Sushma Singh; Ngangkham James Singh; Amit Kumar Maurya<br>**DOI:** https://dx.doi.org/10.5281/zenodo.17489936<br>**Digital Identification Number:** IJOEAR-OCT-2025-29 | **125-131** |

| | | |
|---|---|---|
| **13** | **Development of Water-Resistant Biodegradable Packaging from Agricultural Waste: A Sustainable Approach for Agricultural Product Preservation**<br>**Authors:** Divyanshu Agrawal; Babli Kumari; Ajay Kushwah; Mitul Kumar Agrawal<br>**DOI:** https://dx.doi.org/10.5281/zenodo.17489948<br>**Digital Identification Number:** IJOEAR-OCT-2025-34 | **132-143** |
| **14** | **Effect of Diverse Nutrient Sources and Liquid Organic Manures on Growth Parameters, Weed Count, Weed Dry Weight and Quality Parameters of Sesame (*Sesamum indicum* L.)**<br>**Authors:** V. Tejaswi; A. Upendra Rao; B. Jyothi Basu; S. Govinda Rao<br>**DOI:** https://dx.doi.org/10.5281/zenodo.17489957<br>**Digital Identification Number:** IJOEAR-OCT-2025-36 | **144-151** |
| **15** | **Promotion of Crop- Livestock Integration for Sustainable Resource Utilization**<br>**Authors:** Arun Ninawe<br>**DOI:** https://dx.doi.org/10.5281/zenodo.17489976<br>**Digital Identification Number:** IJOEAR-OCT-2025-37 | **152-163** |
| **16** | **Soil-Plant Nutrient Dynamics and Fertilizer Use Efficiency in Maize & Desmodium Cropping System**<br>**Authors:** Irine Akinyi Odera; Abigael Nekesa Otinga; Ruth Njoroge; Scholastica Mutua<br>**DOI:** https://dx.doi.org/10.5281/zenodo.17489982<br>**Digital Identification Number:** IJOEAR-OCT-2025-39 | **164-178** |
| **17** | **The Terrestrial Hemiptera (Insecta) of the Amrabad Tiger Reserve, Telangana, India**<br>**Authors:** Pradip Chandra Saha; Dhriti Banerjee; M.E. Hassan; Swetapadma Dash; Susmita Khanra; Rakhi Das<br>**DOI:** https://dx.doi.org/10.5281/zenodo.17489995<br>**Digital Identification Number:** IJOEAR-OCT-2025-46 | **179-188** |
| **18** | **Micro Proteins: A Novel Approach for Crop Improvement**<br>**Authors:** Dr. Sabitha. N; Bhavani Saiesha. C; Narasimhulu. R; Naga Madhuri K.V; Reddi Sekhar. M<br>**DOI:** https://dx.doi.org/10.5281/zenodo.17524896<br>**Digital Identification Number:** IJOEAR-OCT-2025-48 | **189-199** |
| **19** | **Sequential Hybrid Approach for Reliable Detection of Rainfall Pauses at the Beginning of the Rainy Season in Senegal: Towards a Predictive Tool for False Starts**<br>**Authors:** Pape El Hadji Abdoulaye Gueye; Cherif Bachir Deme; Diery Ngom; Adrien Basse<br>**DOI:** https://dx.doi.org/10.5281/zenodo.17524380<br>**Digital Identification Number:** IJOEAR-OCT-2025-50 | **200-207** |

| | | |
|---|---|---|
| **20** | **Physiological Screening of Foxtail Millet Genotypes for Water-Use Efficiency and Yield under Rainfed Conditions**<br>**Authors:** D. Venkatesh Babu; T. Raghavendra; Y. S. Satish Kumar<br>**DOI:** https://dx.doi.org/10.5281/zenodo.17524754<br>**Digital Identification Number:** IJOEAR-OCT-2025-51 | **208-215** |
| **21** | **Amphibian Diversity Monitoring during the Monsoon Season in the Western Ghats, with Special Reference to Wayanad**<br>**Authors:** Mr. Sabu V.U; Dr. Jithesh M. P.<br>**DOI:** https://dx.doi.org/10.5281/zenodo.17524782<br>**Digital Identification Number:** IJOEAR-OCT-2025-53 | **216-222** |
| **22** | **Determinants, Constraints, and Prospects of Organic Farming Adoption among Farmers in Jabalpur District of Madhya Pradesh: A Causal-Comparative Study**<br>**Authors:** Laveena Sharma; Deepak pal; Aradhana Singh Rajpoot; Naveen Pal<br>**DOI:** https://dx.doi.org/10.5281/zenodo.17524820<br>**Digital Identification Number:** IJOEAR-OCT-2025-54 | **223-232** |

# Climate Change and Sustainable Development in Africa: Assessing the Rising Threat to Socioeconomic Progress

Douglas Ncube[1*]; Rudo Abigail Togaraseyi[2]

19 Adylinn Road, Marlborough Harare Zimbabwe
*Corresponding Author

Received:- 01 October 2025/ Revised:- 08 October 2025/ Accepted:- 17 October 2025/ Published: 31-10-2025
Copyright @ 2025 International Journal of Environmental and Agriculture Research
This is an Open-Access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (https://creativecommons.org/licenses/by-nc/4.0) which permits unrestricted Non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

***Abstract—***

***Introduction:*** *Climate has been changing drastically in Africa over the last decades. Global temperatures have increased significantly, and extreme weather events have intensified, dominating the disaster landscape in the 21st century in Africa.*

***Background:*** *Climate change leads to increased water crisis, infectious diseases, bio diversity extinction and loss of human life. This means it is a remarkable threat to achieving sustainable development goals in Africa.*

***Problem statement:*** *Climate change has led to economic losses of over US$70 billion in the region over the past fifty years. It is estimated that by 2050, climate change impacts could cost African nations USD$50 billion yearly.*

***Methodology:*** *This paper sought to find out how mankind can prevent the climate change crisis threatening Africa's hard-won development gains. The research was qualitative and based primarily on literature review from secondary data sources.*

***Results:*** *The climate crisis is threatening hard won development gains and intensifying cycles of poverty, fragility and vulnerability across the continent. There is need for African countries to take charge of climate change initiatives which will minimize the impacts of climate change.*

***Conclusion:*** *The impact of climate change cannot go unchallenged as African countries continue to lose billions of dollars annually, desertification is rapidly increasing, cropland is drastically declining, emergence and rapid spreading of pests and diseases and the displacement of thousands of people.*

***Keywords— Climate change, impact, gas emissions, temperature changes, pests and diseases.***

## I. INTRODUCTION

Africa's climate has warmed by 0.3ºC per decade from 1991 to 2022, whereas the global average in the same period was 0.2ºC [1]. Africa has contributed insignificantly to global warming, but its detrimental impacts have affected the region due to its vulnerability. The high level of vulnerability in African countries is driven by the existing low levels of socioeconomic growth in the continent [2]. Climate change has adverse effects globally, but the poor are disproportionately vulnerable to its effects [2]. This is largely attributed to the fact that Africa lacks the resources to afford services and goods required for cushioning and recovering from climate change effects [3]. These extreme events have undermined Africa's capacity to achieve its commitments to meet the Sustainable Development Goals and the African Union Agenda 2063, which indicates Africa's path to inclusive and sustainable economic growth and development [2].

## II. BACKGROUND

Climate change involves many dimensions, including economics, science, politics, and society, and it is a global problem that is felt on local scales [4]. Carbon dioxide, the heat-trapping greenhouse gas, is the primary driver of recent global warming and will linger in the atmosphere for thousands of years [5]. In Africa, climate change's actual and potential consequences significantly affect many aspects of peoples' lives [4].

The Industrial Revolution of the 19th century led to the accumulation in the atmosphere of carbon dioxide, methane, nitrous oxide, chlorofluorocarbon, hydrofluorocarbon, sulfur hexafluoride and nitrogen trifluoride [6]. Climate change generated by

anthropogenic activities is currently gaining global awareness due to apparent alterations in the spatial distribution of rainfall and the impact on many species [7].

Climate change is perceived as a threat multiplier intensifying existing trends, tensions and instability [2]. The impact of climate change on economic growth and sustainable development in Africa is concurrently hindering the ability of African countries to cope with climate change [4]. The most visible and reported consequence is the increasing frequency with which extreme weather events occur, directly affecting the daily lives of people worldwide [8]. Higher temperatures, the drying up of soils, increased pests and diseases, shifts in suitable areas for growing crops and livestock, and increased desertification and erosion are all indications that climate change is already happening and represents one of the most significant environmental, social and economic threats to Africa [9].

According to the 2021 global climate risk index, which analyses the real-world impacts of climate change, for the past two decades, five of the ten countries most affected by climate change in 2019 were in Africa [10]. The countries include Malawi, Mozambique, Niger, South Sudan and Zimbabwe [11]. The slow onset of climate change impacts, such as water scarcity, lower crop and ecosystem productivity, sea level rise, and storm surge, will gradually result in people migrating [11]. The above will result in forced migration and displacement of humans and animals in Africa, and it is estimated that by 2050, at least 113 million people will be displaced [11]. Climate change impacts will not only result in climate-induced migration but will potentially deepen existing vulnerabilities and increase poverty, fragility, conflict and violence [12].

## III. PROBLEM STATEMENT

It is estimated that by 2050, climate change impacts could cost African nations USD$50 billion yearly [2]. The most recent decadal forecast from 2020-2024 shows continued warming and decreasing rainfall, especially in Northern and Southern Africa [13]. Africa now has at least 132 million hectares of degraded cropland, which, coupled with climate change, has led to the susceptibility of millions of people [10]. According to [2], the availability of cropland has drastically declined due to desertification, which has affected at least 45% of Africa's land, of which 55% is at risk of further desertification. Coastal degradation and erosion are also significant challenges, especially in West Africa, where 50% of the coastlines in Benin, Senegal and Togo are eroding, which is anticipated to worsen [2].

Climate change is anticipated to result in a 20% decrease in rainfall, leading to a decrease in crop yields in Africa by 2030 [2]. At least 14.1 million people were internally displaced in Sub-Saharan Africa, including around 11.5 million due to conflict and violence in 2021 [2]. Undernourished people have increased by 45% since 2012 [2]. High-impact events such as tropical cyclone *Idai*, recorded in 2019 in Southern Africa, resulted in the deaths of more than 1000 people, several others remain unaccounted for and the displacement of thousands of families in Malawi, Madagascar, Zimbabwe and Mozambique [10]. Temperature increases and variations in rainfall patterns have drastically affected the populations' health in Africa by exacerbating the predominance of biting insects and the spreading of diseases such as yellow fever and malaria [10]. The high dependency of the economies of Africa on rain-fed agriculture, the dominance of poverty, infrastructural capacities, limited development and the prevalence of poverty and food insecurity make coping with climate change variability a permanent challenge in Africa [14].

## IV. METHODOLOGY

This paper seeks to answer the question: *"how do we as mankind stop/reverse/reduce the crisis threatening Africa's hard-won development gains and intensifying poverty cycles, fragility and vulnerability across the continent due to climate change/global warming?"* This research review is qualitative and based primarily on literature review from secondary data sources. It must be noted that since the review is qualitative in complexion, the research methods have been used together with mostly non-numerical data to find meanings, opinions, and underlying reasons that vary from various sources. It is based mainly on, concerned with and verifiable by observation and experience. Theories on climate change are looked at to confirm and understand statements and comments attributed to climate change.

The literature will be drawn from journals, hand and textbooks, working papers, published and unpublished theses, publications from global climate change conferences and seminars and government documents drawn from the world, including Africa.

This paper defines perceptions of climate change, theories of climate change, climate financing, food and health security, environment and climate change in Africa, climate mitigation and adaptation strategies, recommendations, discussion, and conclusion.

## V. LITERATURE REVIEW

### 5.1 Perceptions of climate change:

Climate change involves the change in climate directly or indirectly attributable to human activities, which, in addition to natural climate erraticism, is observed over comparable periods [15]. Climate change is caused by many factors, including deforestation, ozone layer depletion, and increased carbon dioxide and greenhouse gas (GHG) emissions into the atmosphere [15]. These gases accrue in the atmosphere and result in global warming.

### 5.2 Greenhouse effect:

The greenhouse gas effect refers to the natural warming of the earth when gases in the atmosphere trap heat from the sun that would escape into space [16]. The presence of sunlight makes the earth habitable and it is presumed that 30% of the solar energy that reaches the earth is reflected into space [16]. Approximately 70% of the solar energy passes through the atmosphere and heats the planet to the earth's surface, where it is absorbed by the land, oceans, and atmosphere and heats the planet [17]. Gases that mainly cause the greenhouse effect are carbon dioxide, water vapor, nitrous oxide, methane and fluorinated gases [18].

### 5.3 Theories of climate change:

Seven theories fully explain the occurrences of climate change. The most used/known theory is the anthropogenic global warming theory, which asserts that man-made greenhouse gases, primarily carbon dioxide, have been the predominant cause of global warming during the past five decades [19]. New research points to natural causes of modern warming and stabilising global temperatures, and the theories that support this include bio thermostat, cloud formation and albedo, human forcing, ocean currents, planetary motion and solar variability.

| | |
|---|---|
| Theory 1: Anthropogenic Global Warming | This theory of climate change asserts that human emissions of greenhouse gases, mainly carbon dioxide, methane, and nitrous oxides, are contributing to the disastrous rise in global temperatures [19]. Anthropogenic forcing of the climate system refers to human activities such as industrial activities, transportation, energy production, and agriculture that release many greenhouse gases into the atmosphere [19]. The mechanism whereby this happens is known as the enhanced greenhouse effect, which is referred to as anthropogenic global warming [20]. |
| Theory 2: Bio- thermostat | The biothermostat theory proposes that negative feedback from biological and chemical processes totally or nearly offsets the positive feedback resulting from an increase in carbon dioxide. Such processes act as a global biothermostat to maintain equilibrium temperatures [21]. The processes include carbon sequestration, carbonyl sulfide, iodocompounds, dimethyl sulfide, and other aerosols [22]. |
| Theory 3: Cloud formation and albedo | This theory states that a change in the formation and albedo of clouds creates negative feedback that cancels out all or nearly all of the warming effects of higher levels of carbon dioxide [23]. Cloud albedo measures the portion of solar radiation reflected in space by clouds [24]. Changes in albedo occur as the amount of cloud cover changes. The albedo refers to the reflectivity of surfaces such as snow, ice, sand or clouds, which reflect up to 80% of the solar radiation into space [25]. |
| Theory 4: Human forcing | This theory of climate change states that humans' contribution to greenhouse gas emissions is not the primary cause of climate change [26]. The theory further highlights that the earth's surface transformation through clearing forests, irrigating deserts and building cities is responsible for climate change and human forcing, including urban heat islands, deforestation, aerosols and ozone, coastal development and jet contrails [27]. |
| Theory 5: Ocean currents | The ocean currents theory of climate change states that the global temperature variations over the last century were due to the slowdown of the ocean's Thermohaline Circulation [28]. The thermohaline circulation is the portion of ocean circulation driven by heat and freshwater fluxes across the sea surface and subsequent interior mixing of heat and salt [29]. |
| Theory 6: Planetary motion | The planetary motion theory highlights that most of the warming experienced in the later part of the twentieth century can be explained by natural gravitational and magnetic oscillations of the solar system induced by the planet's movement through space [30]. The oscillations alter solar variations and other extraterrestrial influences of the earth, which drives climate change [31]. |
| Theory 7: Solar variability | The seventh theory of climate change is solar variability, which accounts for most of the warming that took place in the mid-twentieth century and has continued to dominate in the twenty-first century in spite of man-made greenhouse gas emissions [32]. It is alleged that changes in the brightness of the sun are a result of sunspots, which are bursts of energetic particles and radiation that vary in frequency in cycles of roughly 11,87 and 210 years [32]. |

### 5.4 Earth's climate and ice ages:

An ice age can be defined as the result of prolonged cooling, and these are chiefly responsible for the formation of continental ice sheets in both the northern and southern hemispheres and also the growth of glaciers in mountainous parts of the world such as the Himalayas and Alps [33]. It takes substantial geographical time for an ice age to be recorded, and they are not uniformly cold [34]. However, they are also characterised by colder and warmer periods during the overall ice age period [34].

An ice age is caused by a chain reaction of positive feedbacks activated by periodic changes in the earth's orbit around the sun [35]. The feedbacks involving the spread of ice and the release of greenhouse gases work in reverse to warm the earth when the orbital cycle shifts back. Ice ages are caused by some factors, including changes in the earth's orbit, resulting in the earth being closer to the sun and warmer or farther from the sun, where it will be colder [35]. The amount of solar energy from the sun changes, and low energy output cycles also help produce an ice age [35]. Changes in ocean currents and low levels of greenhouse gases, including carbon dioxide, can cause the earth to cool, leading to an ice age [36]. Volcanoes tend to introduce huge amounts of carbon dioxide into the atmosphere, and the lack of volcanoes causes an ice age. Increased volcanic activity can also lead to the end of an ice age [37].

### 5.5 Climate financing:

Climate finance is crucial for enabling Africa to adapt to the mounting consequences of climate change and to guarantee that its future development path is consistent with limiting global warming to no more than 1.5ºC [38]. The development path of Africa will be significant to future emissions given that its energy use is anticipated to grow hastily to meet its development needs, with its share of the world's population estimated to rise from 17% to 40% by 2100 even as the world population is also set to increase from 7.9 billion to almost 11 billion by the end of the century [38].

Determining climate finance in developing economies, especially in Africa, is vital to classify financing gaps and opportunities to guide stakeholders to access, allocate and mobilise climate finance successfully [12]. Such data reinforces international policy processes like the willpower and implementation of a new collective and quantified goal on climate finance and accelerates action [39]. Africa needs approximately USD 2.5 trillion of climate finance between 2020 and 2030, which is an average of USD 250 billion each year(currently, the total annual climate finance flows are only USD 30 billion, comparable to 12% of the amount needed [10].

Public funding alone will not be adequate, given the magnitude of investments needed and current and future limitations on African public domestic resources [40]. Nevertheless, most current climate financing in Africa is from public actors, which is 87% (USD20 billion) [40]. In some instances, private investment can come from shifting existing flows towards climate change action; for example, public and private sector institutions invested at least USD130 billion into fossil fuel companies and projects in Africa [41].

### 5.6 Impact of climate change on African economies:

In spite of contributing only a diminutive amount of global greenhouse emissions, the African continent experiences the deadly consequences of climate change to a top-heavy degree [38]. Climate change is already destabilizing local markets, increasing food insecurity, limiting economic growth and increasing risk for agricultural sector investors [39]. In Sub-Saharan Africa, the GDP could be reduced by up to 3% by 2050, and at least 400 million people in Africa live below the poverty datum line, defined as less than USD$1,90 per day [42].

African countries are likely to record their GDP growth rates falling by 64% by 2100 even if the world successfully reduces global warming to 1.5ºC [43]. Climate-related disasters are also expected to slow GDP per capita growth and increase pressure on budgets and fiscal balance [44]. Climate extremes often result in increased government expenditures and a reduced volume of collected taxes, thereby increasing government debt [45].

African countries' limited resilience against the negative impacts of today's climate is leading to lower growth and development, thereby highlighting the lack of resilience and adaptive capacity [44]. Climate-related disasters are expected to slow GDP per capita growth, and African governments are expected to experience rising pressure on budgets and fiscal balances [44]. The increasing negative impacts of climate on the GDP per capita and the development capacity of African countries could reduce Africa's ability to cope with and adapt to climate change's current and future impacts [44].

### 5.7 Climate change and African tourism:

Tourism is one of Africa's major economic drivers and mainly depends on the climate [46]. It is only natural that environmental changes would have consequences on tourism [46]. Climate change significantly affects tourism and recreation activities. It affects both natural resources supporting tourism and recreation, the nature and duration of tourism and recreation seasons,

tourist health and even the quality of tourism experiences [47]. Climate change impacts that affect tourism in Africa include beach erosion, degradation, wetlands, saline intrusion, droughts, flash floods, landslides and coral reef bleaching [48].

Temperature increases in Africa are expected to intensify the melting of glaciers at mountain tourist destinations across Africa, such as the Rwenzori Mountains in Uganda, Mt Kenya, and Kilimanjaro Mountains in Kenya [49]. Temperature rise is also anticipated to cause severe modifications to coastal tourism destinations in Africa as global warming results in increased coastal flooding due to the thermal expansion of oceans, negatively affecting beaches and tourism properties along the coastline and resulting in implications for tourist experiences and activities [50].

The implications of rising temperatures have also severe repercussions on the comfort of tourists in some destinations for instance in Victoria Falls, Zimbabwe tourists and tour operators are worried about extreme temperatures affecting outdoor tourism and recreational activities[51]. Heat affects game viewing experience for tourists as some animals, particularly big cats, hide under trees and amongst the bushes due to the extreme heat [52]. Animals hide in trees to avoid the heat during the day, negatively influencing game viewing and tourist satisfaction as they do not see as many animals as they would like to see [51].

In the central Drakensberg region, mountain tourism and ecotourism are big tourist attractions in South Africa. They mainly depend on climate conditions, which are now anticipated to be highly unfavourable to activities like mountain hiking and other tourism destination choices [53]. At the Phinda Private Game Reserve in South Africa, rising temperature was perceived to hurt bird species in game reserve, and the vulnerability of birds to excessive temperatures is documented with studies indicating that birds struggle to survive temperatures beyond 35ºC [54]. When temperatures are between 35ºC and 40ºC, birds tend to reduce foraging efficiency and body weight, and this is a disturbing trend at Phinda Game Reserve since it considers birding as one of its unique tourism offerings [54].

Unpredictable weather linked to climate change has brought more frequent and severe droughts and irregular flooding to the *Maasai Mara's* National Reserve in Kenya's fragile ecosystem, leaving the wildebeest increasingly depleted of grazing pasture [55]. This is not only leading to fewer animals migrating to Kenya but also resulting in them staying for less time and eventually affecting the tourism industry in Kenya [55]. Researchers affirm that in the *Maasai Mara* National Game Reserve, a combination of variables, including climate change, has resulted in devastating reductions in wildlife populations [56].

### 5.8 Climate change: food & health insecurity:

Many African areas are known as having climates that are among the most variable in the world on seasonal and decadal time scales [57]. Floods and droughts sometimes occur in the same area within months of each other. These events often lead to famine and widespread disruption of socioeconomic well-being [58]. Agricultural production on the African continent solely depends on rainfall and will be severely compromised, especially for the subsistence farmers. Climate change will result in the decline of crop yields, including sorghum, maize and groundnuts [59]. The achievement of Sustainable Development Goal 2 of zero hunger will be complicated due to the new trends of recurrent floods, droughts, cyclones, rising temperatures and sea levels.

Ocean acidification shrinks ecosystems, resulting in fish shortages; it is also anticipated that by the year 2050, fish production in West Africa is expected to decline by 21% [60]. Lake Tanganyika will likely experience a 30% decline in fish production and undesirable costs across East Africa, including Burundi, the Democratic Republic of Congo, and Tanzania [61]. Carbon dioxide emissions and high temperatures disrupt grain development resulting in low protein content for example it has been observed that during varied growing seasons' edible portions of major staples which include potatoes, rice and wheat decrease by 10-14% [60].

The effects of climate change and adverse weather events on health are gradually becoming an accepted trend that challenges health policy and planning, especially in public and community health [62]. The number of vector-borne diseases is expected to increase and shift the distribution, like what is happening in the highlands of Burundi, Ethiopia, Kenya, and Rwanda, where malaria is already encroaching into areas that did not have any cases of malaria a few years ago [62].

Waterborne diseases are linked with floods, which are known to transfer bacteria, viruses and parasites into drinking water systems, causing an upsurge in waterborne diseases such as cholera, diarrhoea, dysentery, typhoid, cryptosporidiosis and rotavirus [63]. According to [64], bacteria, viruses, protozoa, and other blue-green algae are pathogens and toxins that cause water-related diseases. In 2008, Mozambique recorded a cholera outbreak, which resulted in 70 deaths, and these deaths were documented after severe flooding [63]. After Cyclone *Idai* in 2019, Mozambique again recorded a cholera outbreak with 4,979 cases and six confirmed deaths [63]. There was a major cholera outbreak in Kenya in 2009, which recorded 11,769 cases and 274 deaths [63]. Other climate-sensitive waterborne diseases outlined in many parts of Africa with severe health outcomes are *Buruli* ulcer and schistosomiasis in Ghana and Nigeria [65].

Malnutrition caused by climate change in agriculture and other food systems has been noted across Africa. Also, stunted growth and underweight conditions among children were common during the drought period between 2012 and 2019 [63]. In 2014, it was disclosed that 238,761 children in Ethiopia were treated for severe and acute malnutrition. In Southern Africa, of the 11 million people across nine countries who experienced a food crisis, at least half were children [63].

In Africa, healthcare systems are already strained in their efforts to meet the demands of a growing population using few available resources [66]. Climate change threatens to undermine many public health gains over the past years [66]. Malnutrition, food insecurity, a surge of environmentally sensitive chronic diseases and enhanced viability of pathogenic microbes and their vectors [67].

### 5.9 Environment and Climate Change in Africa:

Due to the earth's lower atmosphere becoming warmer, periodic and more intensified weather events have been observed globally. These are primarily contributed by patterns of natural climate variability such as El Nino and La Nina [26].

#### 5.9.1 El Nino & La Nina effects:

El Niño events are massive climate disturbances in the equatorial Pacific Ocean and occur every two to eight years [68]. Hot waters characterise the El Nino phenomenon at the ocean surface, and this is caused by a strange weakening of the trade winds blowing westward, which allows warm surface waters to reverse their direction eastward [68]. La Nina is caused by a buildup of more relaxed than normal waters in the tropical Pacific, which is the area of the Pacific Ocean between the Tropic of Cancer and the Tropic of Capricorn [69].

#### 5.9.2 Cyclones and Floods:

Cyclones in Africa have affected Mozambique and other Southern African countries [70]. Natural disasters related to heavy rainfall have increased nearly tenfold over the last fifty years, and since 2000, floods have accounted for 66% of disasters recorded in Africa [70]. The floods have also been concentrated in East Africa, with Ethiopia, Kenya, Somalia, South Sudan, and Sudan regularly among the African countries with the largest number of people affected by floods [70]. The list of countries affected by floods varies from year to year for instance in West Africa, Ghana, Niger and Nigeria, and as well as Southern Africa, Angola and Malawi are also severely impacted [70].

Southern African countries were faced with several severe cyclones in the first few months of the year 2022, killing at least 890 people and affecting an additional 2.8 million [71]. These cyclones included Tropical Storm Ana, which resulted in 171 deaths across Madagascar, Malawi, Mozambique, and Zimbabwe in January [71]. The region was also hit by yet other tropical cyclones, which included *Batsirai* and *Emnati*, which killed 136 people in Madagascar in February 2022 [71]. Tropical Storm *Dumako* also killed 14 people in Madagascar and Mozambique in February 2022. Tropical cyclone *Gombe* killed 103 people in Mozambique and Malawi in March, whilst tropical cyclone Jasmine affected 5000 people in Madagascar in April 2022 [71].

Most recently, (March 2023) tropical cyclone Freddy, which is one of the strongest storms recorded in Southern Africa (Indian Ocean), broke the world's record as the longest-lasting tropical cyclone [72]. Cyclones have changed their patterns and now tend to be slow-moving cyclones. Climate change is mainly responsible for making hurricanes wetter, windier and more intense [72]. Cyclone Freddy killed at least 21 people in Madagascar and Mozambique and affected more than 160,000 people in Mozambique, and infrastructure was severely damaged (72).

Data shows that 29 flood disasters have been reported in Chad, Cote d'Ivoire, DRC, Gambia, Ghana, Madagascar, Nigeria, Rwanda, Senegal, Somalia, South Africa, Tunisia, Uganda, Zambia and Zimbabwe [71]. Some of the most extreme flooding has taken place in West Africa, and this includes the floods in Nigeria, which have caused the death of more than 600 people and affected more than 1.3 million people [71]. In Chad, floods also affected 977,000 people in August 2022 and one million in October [71].

Extensive flooding in 2019 in Niger left 9,741 hectares of crops submerged under water [63]. The flooding wiped out crop fields, worsening the dire food insecurity of millions living in the stricken country [63]. Torrential rainfall and floods in the capital city of Chad have left parts of the capital plunged underwater, and thousands of people have been forced to flee their homes [63]. The floods in West Africa resulted from excessive rainfall events contributing to the overflow of rivers and the spillage of dams [63]. In Ghana, the spillage of the *Weija* Dam, which flows from the *Densu* River in October 2022, led to the submergence of numerous communities in Accra and also, the *Bagre Dam*, which flows from White Volta River in Burkina Faso, spilt in September 2022 and caused great havoc on communities living along the Black and White Volta Rivers in Northern Ghana [71]. South Africa also experienced severe flooding in April 2022, whereby 459 people were killed, and a further 40,000 were affected by floods and landslides in the provinces of Kwazulu Natal and Eastern Cape [72].

### 5.9.3 Droughts:

The occurrence of droughts in Africa is mainly due to little or no rain and, in some instances, too much evaporation, causing severe hydrological imbalances [63]. One of the worst droughts reported in the past six decades affected the entire East African region between July 2011 and mid-2012 [63]. The drought led to a severe food crisis across Djibouti, Ethiopia, Kenya, and Somalia, disrupting livelihoods for at least 9.5 million people [63].

There was a prolonged period of dryness in Africa from 2014 to 2016, and many countries were again affected by an extensive drought in 2019 [63]. Countries affected included Angola, Botswana, DRC, Eswatini (formerly Swaziland), Lesotho, Malawi, Mozambique, Namibia, South Africa, Tanzania, Zambia and Zimbabwe. The drought affected the water and agricultural sectors, leading to a severe decline in food and water security in the region [63]. Other reported impacts of drought included daily power outages, which affected at least 17 million people in Southern Africa, as the Kariba dam, which provides about half of Zambia's and Zimbabwe's hydroelectricity needs, was down to between 10-20% capacity [63].

Kariba's water level has been decreasing steadily due to climate change-induced droughts and low inflows from the Zambezi River and its tributaries [73]. Kariba dam is one of the largest man-made dams in the world, providing the bulk of electricity consumed in Zambia and Zimbabwe, and the level of usable water in Kariba tapped by both Zambia and Zimbabwe stood at 2,68% on 7 December 2022, according to the Zambezi River Authority [73]. Diminishing returns from Lake Kariba's hydroelectric plant demonstrate how climate change threatens basic amenities such as water and power supply, and the erratic downpours have done little to replenish the lake's reservoir levels [74]. The *Gove* Dam's hydropower supply in Angola was reduced to half its standard capacity, affecting 2 million people in the Angolan cities of *Huambo, Kuito* and *Caala* [63].

### 5.10 Heat waves & wildfires:

In 2022, several parts of northern and central Africa saw damaging wildfires, and in the Central Africa Republic, amid high temperatures and drought, fires forced 500 families to seek emergency shelter, which then also led to outbreaks of malaria, cholera and polio [71]. Algeria also experienced severe wildfires and extreme heat in 2022, and more than 100 fires were reported in North East Algeria, killing 44 people and causing a further 2,000 to evacuate [71]. Livelihoods of over 6,000 people, including farmers, lost dozens of hectares, nearly a thousand fruit trees and more than 400 heads of livestock [71].

### 5.11 Wildlife:

New research shows that warming temperatures are affecting the reproductive success of African wild dogs, and their breeding pattern is being compromised [75]. The African wild dog is an endangered large carnivore scattered across the continent, and its pups are usually raised in the cooler months each year [75]. It has been observed that they are adapting to warm temperatures and giving birth later each year as they track a dwindling cool period. In the Okavango Delta in Botswana, where the largest species remains, the birthing dates of these wild dogs have shifted and are occurring more than three weeks later than they did some thirty years ago [75].

Many iconic wildlife species have been pushed to extinction due to different non-climate stressors like poaching and illegal hunting in the past decades [76]. However, climate change has emerged as a silent threat to wildlife [76]. Elephants will be affected because they are the largest mammals with significant water needs. Elephants can use up to 150 -300 litres daily for bathing, spraying on their bodies to cool down, and drinking [76]. These communal water-based activities are essential to their social makeup as a species, and the decline of water sources will significantly impact their well-being. Hippos tend to spend more than 12 hours per day in water bodies ranging from rivers to man-made ponds during the dry seasons, and the depletion of natural water habitats due to rising temperatures presents the species with various challenges [76]. Overcrowding of the hippos allows for the faster transmission of diseases while fighting over shrinking territories, which has resulted in the loss of male hippos [76].

Lions are also susceptible to extreme weather conditions like droughts, which disrupt their reproductive cycles [76]. Cheetahs already suffer from a lack of genetic diversity due to breeding in fragmented populations. As a result, reproduction rates are poor, and the surviving offspring are more vulnerable to diseases and their ability to live in various places [76]. Habitat loss has also radically reduced populations of giraffes that were once common across the continent, and though they can withstand extended dry seasons, ecological limits like rivers may hinder their ability to disperse as climatic conditions change [76].

### 5.12 Expansion of deserts and migration conflicts in Africa:

Desertification is an increasingly pervasive problem as climate change alters weather patterns, leaving people with hyper-arid conditions [77]. The Sahara desert is no exception; it is steadily growing across 11 countries and will soon cover more [77]. Deserts typically form in the subtropics due to airflow rising from the hot equator and dropping back down around the tropics [78]. As tropical latitudes shift polewards at a rate of 48 kilometers annually, scientists report a corresponding increase in desert

expansion. [78].In the Kalahari region, temperatures have risen from about 34º C in the 1990s to well over 36º C in the present day, and this equates to a warning rate of about 1º C per decade, a rate five times faster than the global average of about 0.2º C per decade [79].

Lake Chad, a landmark in the transitional region between the desert in the fertile savannas, the Sahel, is a good pointer of the slow but steady desertification that is occurring, and of the 20 million beneficiaries of Lake Chad's water, 80- 90% live off agriculture, livestock and fisheries [78]. The decline of the region's lifeblood resources threatens it with food insecurity and conflict [78]. Libya, which also used to be a non-desert in 1920, is now mostly desert, having experienced a 500-kilometer advance of the Sahara during the dry season [78].

On the Lake Chad Basin, around 30 million people in Cameroon, Chad, Niger and Nigeria are competing over considerably shrinking water sources which, from 1960, have lost 90% of their surface water [80]. Displacement, hunger and malnutrition are rampant, and this has contributed to increasing abductions, killing and rights violations [10]. As a result, there has been an increase in the growth of terrorist organizations, causing 10 million people to need humanitarian assistance [10]. In Chad, farmers and herdsmen tend to struggle over the limited water left, and this forces herdsmen to migrate in search of greener pastures, resulting in conflicts [80].

In North East Nigeria, where more than half of the population makes their living from farming, fishing and livestock production, increased aridity has destroyed many livelihoods, making them vulnerable to recruitment by Boko Haram [80]. Its attacks have grown in brutality and consistency since December 2020, when they attacked 110 rice farmers, leaving them dead. Since Boko Haram's formation in 2009, there have been nearly 40,000 fatalities and displacement of 2,4 million people around the Lake Chad Basin [80].

The Horn of Africa, encompassing Eritrea, Ethiopia, Kenya and Somalia, is also afflicted by climate-driven conflict, and droughts also impact over 13 million people, encouraging induced migration and, eventually, tensions and terrorism [10]. In Ethiopia in Tigray, a region that is already hosting 100,000 Eritrean refugees suffering from drought, war began in November 2020 due to the position of its communities, which has become extremely unstable [80]. The effects of climate change determine these conflict patterns of violence arising from forced migration into contested space [80].

### 5.13 Increase in the frequency of new and old pests and diseases:

Climate change drives the spread of new and old pests and diseases because it affects the population size, survival rate, geographical distribution of pests and the intensity, development, and geographical distribution of diseases [81]. There is an increase in Africa in the whitefly population, which transmits *torrado crini* and *begomo* virus to plants like potatoes and cotton [81].

Pests like fall armyworm, which feeds on many crops, including maize, sorghum and millet, *and tephritid* fruit flies, which damage fruit and other crops, have increased due to warmer climates [82]. Desert locusts, the world's most destructive migratory pests, are also anticipated to change their migratory routes and geographical distribution due to climate change [82]. The fall armyworm arrived in Africa and spread across the continent from America in 2016, causing an estimated $9.4 billion in yearly losses on crops [83]. African farmers are also struggling to contain the larger grain borer which reached the continent in the 1970s and can destroy up to 4 % of stored maize in just four months [83]. The large grain borer threatens cassava chips and can potentially cause losses of up to 50% in three months [83]. The grain borer is anticipated to continue spreading as climatic conditions become favourable [83].

Climate change intensifies livestock diseases; some climate-sensitive diseases include Rift Valley fever, ticks and tick-borne diseases, and trypanosomiasis [84]. Additionally, to these direct impacts, climate change also has indirect effects on animal diseases, such as an increased rate of development of parasites and pathogens, exposure to new pathogens and vectors as a result of increased pest range, and altered ecosystem structure and function [84]. Evidence shows that some critical livestock diseases, such as bluetongue, have already expanded due to climate change, and some models predict that trypanosomiasis costs farmers in East Africa $2 billion a year [84]. East Coast fever kills at least one animal in Africa every thirty seconds, and Rift Valley fever has reduced exports from Africa by at least 75% [84].

Aquaculture, which is still in its infancy in Africa, is largely affected by climate change. African countries, including Egypt, Namibia, and Nigeria, are making considerable investments in aquaculture, but they are currently experiencing higher cumulative mortalities and faster development of diseases [84]. Reports of two significant climate-sensitive diseases, namely epizootic ulcerative syndrome (EUS) in fish since 2007 in Botswana, Namibia and Zambia and shrimp white spot diseases since 2011 in Mozambique, are clear examples of how pathogens can jump national and international boundaries and bring about catastrophic impacts on communities [84]. EUS occurs in natural freshwater systems, and extreme weather events like flooding can distribute EUS over thousands of kilometres [84].

## VI. RECOMMENDATIONS

Africa faces significant challenges due to changes in the global climate. While international agreements to minimize the drivers of future climate change are set to benefit African countries, they also have to take measures to adapt to likely future climate challenges.

- Environmental issues should be at the forefront of the global sustainable development agenda, and eco-friendly practices like water harvesting, improvement of the land drainage system through careful disposals of plastics and conservation of high carbon ecosystems such as forests, wetlands and peat lands, among others, will mitigate climate change.
- African governments should combine climate change risks in development and macroeconomic planning by having macroeconomic forecasts that include climate-induced economic risks. This requires capacity building and analytical tools for government experts to analyse climate and socioeconomic data.
- The development of adaptive water management techniques, including learning-based approaches and flexible solutions, is vital for African countries. These techniques can help African countries adjust to uncertain hydrological changes. Seawater desalinization is one of the ideal climate change strategies because it enhances water security through the reliability of supply, independent of climate, rainfall, and many other challenges.
- There is a need for African countries to maintain wetlands, which are biodiversity hotspots that contribute to building climate resilience. Wetlands are responsible for sequestering carbon in the soil and trapping carbon dioxide from the atmosphere, making them nature's solution to the climatic emergency.
- African countries must focus on research and development to ameliorate approaches for forecasting and predicting pests and disease outbreaks and mechanisms to manage these outbreaks. The use of recent technological tools like the Mobile and Real-time Plant Disease (MARPLE), which tests pathogens such as wheat rust in near real-time, gives results within 48 hours, and also allows for detection, might be crucial to mitigating the devastating impacts of pests and diseases in Africa.
- African governments should concentrate on buttressing existing delivery systems and institutions as well as insurance and social protection strategies, which are meant to enhance health, security and livelihoods in the near term.
- African governments and citizens must change their energy production and usage models to limit greenhouse gas emissions, reducing climate change's magnitude. There is a need to raise awareness of the use of renewable systems to adapt to changing technologies in the energy sector because Africa itself commands a more significant potential for renewable energy in the form of hydroelectric and wind.
- African countries must not solely benefit from advice; they must be actively involved in dialogues on how to deal with climate change issues and devise evocative solutions. The use of indigenous knowledge needs to be integrated into Africa's economic, agricultural, scientific, and governance systems.
- Companies that heavily pollute need to be held more accountable, and African governments must pressure these industries to resort to clean energy.
- Capacity building for specialists in meteorological and statistical offices needs to be facilitated so that they can efficiently merge and analyse climate and socioeconomic data. Collaboration between these units and relevant ministries in planning and forecasting could be strengthened.

## VII. DISCUSSION

African countries will be the worst affected by climate change due to several reasons, which consist of the way the African society is largely dependent on rainfall to grow food, the African climate system, which is controlled by a highly complex mix of large-scale weather systems from distant parts of the planet and in comparison with almost all other inhabited regions is greatly understudied [85]. The capacity for adaptation to climate change is low; poverty equates to reduced options at the individual level, while governance generally fails to prioritise and act on climate change [86].

The climate crisis is threatening hard-won development gains and intensifying cycles of poverty, fragility and vulnerability across the continent [87]. The impact of climate change in Africa exceeds food insecurity. Climate change leads to water crisis, infectious diseases, bio diversity extinction and direct loss of human life [88]. This means it is a remarkable threat to achieving sustainable development goals in Africa. Africa already lags in realizing sustainable development goals due to socioeconomic and political challenges prevailing in the continent [89]. Recurrent climate extremes are indicators of change in patterns, timing

and amount of rainfall [90]. They are major drivers of vulnerability in many agroecological zones in Africa, leading to changes in crop yields and higher food prices [90].

The climate crisis is a global problem, and all countries face this catastrophe. Governments and large businesses must join in this fight to implement change. The climate crisis is everyone's problem, and significant work must be done [91]. Plenty of debate and discourse about the responsibility of climate crisis does not fall on the shoulders of a selected group of people. The delay in action will probably cost the future if serious steps are not taken soon [92]. There is a general lack of will to act and change by some governments profiting from climate change. Initiatives have to be put in place to reduce the large carbon footprint humans have left all over the world, but who is to blame for the climate crisis that has taken place along with an unspoken, unfair and unrealistic responsibility placed on the average person to do their part to help combat the deterioration of the earth [93]. Latest reports show that Western countries and Asian countries are to blame for climate change, and the top five carbon dioxide emitters include [94]:

| | |
|---|---|
| China | 30% |
| USA | 13.5% |
| India | 7.3% |
| Russia | 4.7% |
| Japan | 2.9% |

African countries contribute less than 4% of global greenhouse gas emissions but bear the brunt of the results of climate change. Coping with climate variability seems to be a key challenge for most African countries [95]. The high dependence of the African economies and rural people of the continent on rain-fed agriculture, poverty and food insecurity and the limited development of institutional and infrastructural capacities make coping with climate variability a permanent challenge in Africa [96]. The continent is already contending with more frequent climate-related disasters, hotter weather, and erratic rainfall, bringing human tragedy, social upheaval and economic disruptions [97].

The rising temperatures will influence the habitability of some places, and climate change related migration will result from the diminishing agricultural prospects [98]. People will not only be forced to move from rural to urban areas, but movement will also be across national boundaries. Migration related to climate change is connected to conflict in Africa, especially in the Sahel and Darfur, which has been cited as the world's first climate conflict [99]. Climate change has resulted in an increase in conflicts and will continue to do so in the future.

Scientists have discovered that the survival of the Amazon rainforest the largest jungle in the world depends heavily on the Sahara Desert, which holds the title of the world’s largest sand desert [100]. There is a vital connection between the Sahara and the Amazon, tied to the movement of desert dust across the Atlantic Ocean. The Sahara provides the Amazon with essential phosphorus through dust plumes that travel across the ocean [100].This process occurs mainly because hot desert winds lift and carry dust, phosphorus, and other nutrients, which are then deposited over the South American rainforest. These nutrients nourish the local vegetation and support natural plant growth. The Amazon is known for having nutrient-poor soils about 90% of its soil lacks phosphorus which has made large-scale farming nearly impossible in the region [100].

Every year, tens of thousands of tonnes of nitrogen are lost from the Amazon through its vast river systems. To replace the lost phosphorus, the forest relies on the nutrient-rich dust blown in from the Sahara [100]. Scientists estimate that the Sahara delivers approximately **22,000 tones** of phosphorus annually to the Amazon, which closely matches the amount the rainforest loses through river runoff [101].The arid conditions in deserts are ideal for the formation and concentration of important minerals like **gypsum, borates**, **nitrates**, and **potassium**. These minerals accumulate as water carrying them evaporates. Additionally, desert sands serve as significant **carbon sinks,** much like forests. Since **carbon dioxide** is a major contributor to global warming, desert sands may play a critical role in preventing more carbon dioxide from entering the atmosphere.

At the COP 27 conference held in November 2022 in Egypt, European countries declared they would make cash pledges to support Africa’s climate adaptation fund [102]. However, the funds are not adequate because climate change's impacts require huge investments. This comes at a time when some European leaders acknowledge that climate change is real and has permanent effects. African leaders, therefore, need to utilize this opportunity to focus more on building resilient climate change systems [103].

## VIII. 8.0. CONCLUSION

Climate change presents a considerable and growing challenge globally, and the implications of climate change will be more significant for future generations if action is not taken as soon as possible. Climate change is a global issue that has an effect on everyone and profoundly impacts the economies, society, and environment. The impact of climate change cannot go unchallenged as African countries continue to lose billions annually, desertification is rapidly increasing, cropland is drastically declining, emergence and rapid spreading of new and old pests and diseases and the displacement of thousands of people due to weather-related disasters.

Climate change, hence, needs/demands compelling cooperation and shared responsibility. The world cannot afford to fail to combat climate change since there is so much at stake, especially for Africa. Strong action is required to reduce emissions in order to alter the future path of human-induced warming, and action is required to begin adapting to the warming that is already taking place and is likely to continue.

## 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 authors Douglas Ncube PhD and Rudo Abigail Togaraseyi MA certify that they have no affiliation 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 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] J. Bamanya, *Indigenous Technical Knowledge in the Face of Climate Change Uncertainties: The Case of Nakisunga Sub County, Mukono District, Uganda*. MSc Thesis, University of Guelph, School of Environmental Design and Rural Development, 2017.

[2] World Meteorological Organisation, "State of climate in Africa highlights water stress and hazards," *United Nations News*, 2022. [Online]. Available: https://news.un.org/en/story/2022/09/1126221. [Accessed: 11-Mar-2024].

[3] United Nations Environment Programme, "Responding to climate change," *UNEP Africa*, 2020. [Online]. Available: https://www.unep.org/regions/africa/regional-initiatives/responding-climate-change. [Accessed: 10-Mar-2024].

[4] P. Holden, "A peaceful environment or a hostile climate," 2009. [Online]. Available: https://www.files.ethz.ch/isn/136704/PAPER220.pdf. [Accessed: 14-Mar-2024].

[5] S. C. Moser, "Communicating climate change: History, challenges, process and future directions," *Wiley Interdisciplinary Reviews: Climate Change*, 2010. [Online]. Available: https://doi.org/10.1002/wcc.11. [Accessed: 11-Apr-2024].

[6] R. S. Weart, *The Discovery of Global Warming*. Cambridge, MA: Harvard University Press, 2008.

[7] A. L. Angert, S. L. LaDeau, and R. S. Ostfeld, "Climate changes and species interactions: Way forward," 2013.

[8] M. T. Niles and N. D. Mueller, "Farmer perceptions of climate change: Associations with observed temperature and precipitation trends, irrigation and climate beliefs," 2016.

[9] D. Tadesse, "The impact of climate change in Africa," 2010. [Online]. Available: https://www.files.ethz.ch/isn/136704/PAPER220.pdf. [Accessed: 29-Mar-2024].

[10] World Bank, "Climate change could further impact Africa's recovery pushing 86 million Africans to migrate within their own countries by 2050," 2021. [Online]. Available: http://www.worldbank.org/press/releases/2021/10/27. [Accessed: 29-Mar-2024].

[11] N. P. Simpson, "Climate change will force up to 113 million people to relocate within Africa by 2050," 2022.

[12] World Bank, "Climate Action in 2022: A look back at the World Bank's climate work for the past year," 2022. [Online]. Available: https://www.worldbank.org/en/news/feature/2022/12/16/climate-action-in-2022-a-look-back-at-the-world-bank-s-climate-work-for-the-pastyear. [Accessed: 08-Apr-2024].

[13] United Nations Framework Convention on Climate Change, *Annual Report 2020*. [Online]. Available: https://unfccc.int/sites/default/files/resource/UNFCCC_Annual_Report_2020.pdf. [Accessed: 02-Apr-2024].

[14] M. Denchak, "Are the effects of climate change really that bad?" *NRDC*, 2022. [Online]. Available: https://www.nrdc.org/stories/are-effects-global-warming-really-bad. [Accessed: 29-Apr-2024].

[15] M. D. Manstrandrea and S. H. Schneider, "Global Warming," *Microsoft Encarta Online Encyclopedia*, 2009.

[16] M. Denchak, "Greenhouse effect," *NRDC*, 2019. [Online]. Available: https://www.nrdc.org/stories/greenhouse-effect-101. [Accessed: 27-Mar-2024].

[17] Koehler-Munro and Goddard, *Climate Change, Agriculture & Rural Development*. Alberta: ACVRC, 2010.

[18] Environmental Protection Agency, "Climate change indicators: Arctic glaciers," *EPA*, 2022. [Online]. Available: https://www.epa.gov/climate-indicators/climate-change-indicators-arctic-glaciers. [Accessed: 25-Apr-2024].

[19] M. Beniston, "Anthropogenic forcing of the climate system," in *Climatic Change and its Impacts*, Advances in Global Change Research, vol. 19. Dordrecht: Springer, 2004. [Online]. Available: https://doi.org/10.1007/1-4020-2346-4. [Accessed: 21-Mar-2024].

[20] A. Gore, *An Inconvenient Truth: The Planetary Emergency of Global Warming and What We Can Do About It*. 2006.

[21] C. Idso and S. F. Singer, *Climate Change Reconsidered*. Chicago, IL: The Heartland Institute, 2009.

[22] C. D. O'Dowd, "Marine aerosol formation from biogenic iodine emissions," 2002.

[23] Y. C. Sud, G. K. Walker, and K. M. Lau, "Mechanisms regulating deep moist convection and sea-surface temperatures in the tropics," *Geophysical Research Letters*, vol. 26, no. 8, 1999.

[24] R. Müller, J. Trentmann, C. Träger-Chatterjee, R. Posselt, and R. Stökli, "The role of the effective cloud albedo for climate monitoring and analysis," *Remote Sensing*, 2011.

[25] R. S. Lindzen, M. D. Chou, and A. Y. Hou, "Does the Earth have an adaptive infrared iris?" *Bulletin of the American Meteorological Society*, 2001.

[26] R. Pielke, "Climate change: The need to consider human forcing besides greenhouse gases," 2009.

[27] T. Matsui and R. A. Pielke, "Measurement-based estimation of the spatial gradient of aerosol radiative forcing," 2006.

[28] W. M. Gray, "Global temperature change," presented at the 2nd Annual AccuWeather Hurricane Summit, Houston, Texas, 2007.

[29] S. Rahmstorf, "Thermohaline circulation," in *Reference Module in Earth Systems and Environmental Sciences*, 2015. [Online]. Available: https://www.sciencedirect.com/topics/earth-and-planetary-sciences/thermohaline-circulation. [Accessed: 06-Apr-2024].

[30] M. Milankovic, *Canon of Insolation and the Ice-Age Problem (Kanon der Erdbestrahlung und seine Anwendung auf das Eiszeitenproblem)*. Belgrade: Royal Serbian Academy of Mathematical and Natural Sciences, 1941.

[31] N. Scafetta, "Climate change and its causes: A discussion about some key issues," *La Chimica e l'Industria*, vol. 1, 2010.

[32] K. S. Carslaw, R. G. Harrison, and J. Kirkby, "Cosmic rays, clouds, and climate," *Science*, vol. 298, pp. 1732–1737, 2002.

[33] M. Peterson, "Climate explained: What is an ice age and how often do they happen," 2012.

[34] Z. Hausfather, "How the rise and fall of carbon dioxide levels influenced the ice ages," 2020.

[35] D. Herring and R. Lindsey, "Hasn't Earth warmed and cooled naturally throughout history?" 2020.

[36] C. Jones, *Prehistoric Changes in Climate Change Does Not Disprove Current Climate Science*, 2022.

[37] The Royal Society, *Climate Change: Evidence and Causes*, 2020. [Online]. Available: https://royalsociety.org/~/media/royal_society_content/policy/projects/climate-evidence-causes/climate-change-evidence-causes.pdf. [Accessed: 02-Apr-2024].

[38] A. Bhattacharya, *The Criticality of Climate Finance for Africa*, 2022. [Online]. Available: https://www.brookings.edu/blog/africa-in-focus/2022/02/08/the-criticality-of-climate-finance-for-africa/. [Accessed: 17-Apr-2024].

[39] S. Guzman, G. Dabrovich, A. Balm, and C. Meattle, *Climate Finance Needs of African Countries*, 2022.

[40] Climate Policy Initiative (CPI), *Global Landscape of Climate Finance 2021*, 2021. [Online]. Available: https://www.climatepolicyinitiative.org/publication/global-landscape-of-climate-finance-2021/. [Accessed: 19-Mar-2024].

[41] I. Gueskens and H. Butijn, *Locked Out of a Just Transition: Fossil Fuel Financing in Africa*, 2022.

[42] C. A. Ray, *The Impact of Climate Change on Africa's Economies*, 2021. [Online]. Available: https://www.fpri.org/article/2021/10/the-impact-of-climate-change-on-africas-economies/. [Accessed: 15-Apr-2024].

[43] *The Guardian*, *Climate Crisis Will Have Huge Impact on Africa's Economy*, 2022. [Online]. Available: https://www.theguardian.com/world/2022/nov/09/climate-crisis-huge-impact-africa-economies-study-says. [Accessed: 05-Apr-2024].

[44] African Development Bank, *Climate Change in Africa*, 2019. [Online]. Available: https://www.afdb.org/en/topics-and-sectors/sectors/climate-change. [Accessed: 18-Mar-2024].

[45] African Development Bank, *Climate Change Impacts on Africa's Economic Growth*, 2020. [Online]. Available: https://www.afdb.org/en/documents/climate-change-impacts-africas-economic-growth. [Accessed: 31-Mar-2024].

[46] S. Rayamajhi, "Linkage between tourism and climate change: A study of the perceptions of stakeholders along the Annapurna trekking trail, Nepal," *Tourism and Development Review*, vol. 2, no. 1, 2012. [Online]. Available: https://doi.org/10.3126v2il.7380. [Accessed: 23-Mar-2024].

[47] K. Dahiya and D. K. Batra, "Tourist decision making: Exploring the destination choice criteria," *Asian Journal of Management Research*, vol. 7, no. 2, 2016.

[48] D. M. Imbwaga, *Tourism and Climate Change*, 2019. [Online]. Available: https://www.youth4nature.org/stories/tourism-climatechange. [Accessed: 28-Mar-2024].

[49] M. Nyamwange, *Impacts of Climate Change on Tourism in Kenya*, 2016. [Online]. Available: http://jgesnet.com/journals/jges/Vol_4_No_2_December_2016/1.pdf. [Accessed: 18-Apr-2024].

[50] D. Scott, M. C. Simpson, and R. Sim, *The Vulnerability of Caribbean Coastal Tourism to Scenarios of Climate Change Related to Sea Level Rise*, 2012.

[51] K. Dube and G. Nhamo, *Tourist Perceptions and Attitudes Regarding the Impacts of Climate Change on Victoria Falls*, 2020.

[52] C. J. Lennard, G. Nikulin, A. Dosio, and W. Moufouma-Okia, *On the Need for Regional Climate Information over Africa under Varying Levels of Global Warming*, 2018.

[53] D. Scott and C. Lemieux, "Weather and climate information for tourism," *Procedia Environmental Sciences*, vol. 1, no. 1, 2010.

[54] Y. Satake, *Deployment of Wi-Fi Services for Foreign Tourists in a Mountainous Area of Japan*, 2019.

[55] N. Bhalla, *In Kenya, Climate Change Shrinks Maasai Mara Wildebeest Migration*, 2022. [Online]. Available: https://www.reuters.com/business/cop/kenya-climate-change-shrinks-maasai-mara-wildebeest-migration-2022-11-03/. [Accessed: 17-Mar-2024].

[56] K. L. Rotich, R. Ogola, B. Makopondo, N. K. Kiprutto, and D. W. Barasa, *Perceived Effect of Climate Change on Tourism Sustainability in Maasai Mara National Game Reserve, Kenya*, 2015.

[57] P. J. Ashton, "Avoiding conflicts over Africa's water resources," *Ambio*, vol. 31, no. 3, 2002.

[58] Africa Centre for Strategic Studies, *Cyclones and More Frequent Storms Threaten Africa*, 2022. [Online]. Available: https://africacenter.org/spotlight/cyclones-more-frequent-storms-threaten-africa/. [Accessed: 10-Mar-2024].

[59] M. Boko, I. Niang, A. Nyong, C. Vogel, A. Githeko, M. Medany, B. Osman-Elasha, R. Tabo, and P. Yanda, *Climate Change 2007: Impacts, Adaptation and Vulnerability*, 2007.

[60] *Bloomberg U.S. Edition, Horn of Africa Drought Kills Over 1.5 Million Livestock: On Brink of Catastrophe*, 2022.

[61] V. W. Lam, W. Cheung, and S. Swark, "Climate change on fisheries in West Africa: Implications for economic, food, and nutritional security," *African Journal on Marine Science*, vol. 3, no. 4, 2012.

[62] C. Caminade, S. Kovaks, J. Rocklov, A. M. Tomkins, A. P. Morse, G. Coton, H. Stenlund, P. Martens, and J. Lloyd, *Climate Change and Global Malaria*, 2014.

[63] British Broadcasting Corporation (BBC), *How Africa Will Be Affected by Climate Change*, 2019. [Online]. Available: https://www.bbc.com/news/world-africa-50726701. [Accessed: 09-Apr-2024].

[64] J. Trtanj, L. Jantarasami, J. Brunkard, T. Collier, J. Jacobs, E. Lipp, S. McLellan, H. Paerl, and J. Ravenscroft, *Climate Impacts on Water-Related Illness*, 2016.

[65] P. Tschakert, V. Ricciardi, E. Smithwick, M. Machado, D. Forring, H. Hausermann, and L. Bug, "Situated knowledge of pathogenic landscapes in Ghana: Understanding the emergence of Buruli ulcer through qualitative analysis," 2015.

[66] S. J. Coates, W. Enbiale, M. D. P. Davis, and L. K. Anderson, "The effects of climate change on human health in Africa: A dermatologic perspective," 2020.

[67] E. Ludi, L. Jones, and S. Levine, *Changing Focus? How to Take Adaptive Capacity Seriously: Evidence from Africa Shows That Development Interventions Could Do More*, ODI Briefing Paper 71, Overseas Development Institute (ODI), London, UK, 2012.

[68] M. Vikas and G. S. Dwarakish, "El Niño: A review," *International Journal of Earth Sciences & Engineering*, 2015.

[69] National Geographic Society, *La Niña*, 2022. [Online]. Available: https://education.nationalgeographic.org/resource/la-nina. [Accessed: 27-Apr-2024].

[70] Africa Centre for Strategic Studies, *Cyclones and More Frequent Storms Threaten Africa*, 2022. [Online]. Available: https://africacenter.org/spotlight/cyclones-more-frequent-storms-threaten-africa/. [Accessed: 10-Apr-2024]

[71] D. Dunne, *Africa's Unreported Extreme Weather in 2022 and Climate Change*, 2022. [Online]. Available: https://www.carbonbrief.org/analysis-africas-unreported-extreme-weather-in-2022-and-climate-change/. [Accessed: 09-Apr-2024].

[72] World Meteorological Organization, "Storm Freddy brewing again," *The Daily News*, 11 Mar 2023.

[73] Z. Hansrod, *Record Low Kariba Dam Levels See Zimbabwe and Zambia Facing Drastic Power Cuts*, 2022. [Online]. Available: https://www.rfi.fr/en/africa/20221212-record-low-levels-at-kariba-dam-leave-zimbabwe-zambia-facing-drastic-power-cuts. [Accessed: 17-Apr-2024].

[74] *New Africa Daily, Zimbabwe Faces Power Outages as Hydroelectric Dam Reservoir Levels Drop*, 2020. [Online]. Available: https://newafricadaily.com/drought-zambia-zimbabwe-face-power-outages-hydroelectric-dam-reservoir-levels-drop. [Accessed: 28-Mar-2024].

[75] N. R. Jordan, B. Abrahms, D. Rabaioth, K. Rafiq, and R. Woodroffe, *Climate Change is Causing Endangered African Wild Dogs to Give Birth Later Threatening the Survival of the Pack*, 2022.

[76] S. Wasiye, *Supporting Wildlife Species in the Face of Climate Change*, 2022.

[77] O. Mulhern, *Is the Sahara Desert Growing?*, 2021. [Online]. Available: https://earth.org/data_visualization/the-past-present-and-future-of-the-sahara-desert/. [Accessed: 11-Apr-2024].

[78] N. Thomas and N. Sumant, "20th Century climate change over Africa: Seasonal hydroclimate trends and Sahara Desert expansion," *Journal of Climate*, vol. 31, no. 9, 2018.

[79] N. B. Pattison, *Hotter Kalahari Desert May Stop Hornbills Breeding Within Years*, 2022.

[80] J. Hudson, *How Is Climate Change Driving Conflict in Africa?*, 2021. [Online]. Available: https://reliefweb.int/report/world/how-climate-change-driving-conflict-africa. [Accessed: 19-Mar-2024].

[81] A. Doody, *Pests and Diseases and Climate Change: Is There a Connection?*, 2020. [Online]. Available: https://www.cimmyt.org/news/pests-and-diseases-and-climate-change-is-there-a-connection/. [Accessed: 04-Apr-2024].

[82] P. Mafongoya, A. Gubba, V. Moodley, D. Chapoto, L. Kisten, and M. Phophi, *Climate Change and Rapidly Evolving Pests and Diseases in Southern Africa*, 2019.

[83] L. Y. Estelle, *Climate Change Means Farmers in West Africa Need More Ways to Combat Pests*, 2022. [Online]. Available: https://theconversation.com/climate-change-means-farmers-in-west-africa-need-more-ways-to-combat-pests-191810. [Accessed: 04-Apr-2024].

[84] D. Dinesh, B. Bett, R. Boone, D. Grace, J. Kinyangi, J. Lindhahl, C. V. Mohan, J. Rairez-Villegas, T. Robinson, T. Rosenstock, J. Smith, and P. Thornton, *Impact of Climate Change on African Agriculture: Focus on Pests and Diseases*, 2015.

[85] R. U. Onyeneke and D. K. Madukwe, "Adaptation measures by crop farmers in southeastern rainforest zone of Nigeria to climate change," 2010.

[86] Intergovernmental Panel on Climate Change (IPCC), *Climate Change 2022: Mitigation of Climate Change*, 2022. [Online]. Available: https://www.ipcc.ch/report/ar6/wg3/. [Accessed: 08-Mar-2024].

[87] L. Kemoe, P. Mitra, and C. D. Okou, *How Africa Can Escape Chronic Food Insecurity Amid Climate Change*, 2022.

[88] M. D. Manstrandrea and S. H. Schneider, *Global Warming, Microsoft Encarta Online Encyclopedia*, 2009.

[89] P. Ahairwe, *The Paradox of Climate Change: How Africa Can Step Up Climate Action to Lighten Its Vulnerability*, 2019. [Online]. Available: https://ecdpm.org/work/the-paradox-of-climate-change-how-africa-can-step-up-climate-action-to-lighten-its-vulnerability. [Accessed: 16-Mar-2024].

[90] K. S. Mpakairi, H. Ndaimani, P. Tagwireyi, M. Zvidzai, and T. H. Madiri, *Futuristic Climate Change Scenario Predicts a Shrinking Habitat for the African Development: Evidence from Hwange National Park, Zimbabwe*, 2020.

[91] I. Suarez, *Strategies That Achieve Climate Mitigation and Adaptation Simultaneously*, 2020.

[92] D. Etongo, *Climate Change Adaptation in Seychelles: Actors, Actions, Barriers and Strategies for Improvement*, 2019.

[93] G. Siebritz, *The Blame Game of the Climate Crisis*, 2022. [Online]. Available: https://www.careersportal.co.za/features/the-blame-game-of-the-climate-crisis. [Accessed: 15-Mar-2024].

[94] I. Tiseo, "Largest global emitters of carbon dioxide in 2021 by country," *Statista*, 2022. [Online]. Available: https://www.statista.com/statistics/271748/the-largest-emitters-of-co2-in-the-world/. [Accessed: 15-Apr-2024].

[95] L. Jones, *Social Barriers to Adaptation: Exploring Implications and Identifying Options for Adaptation Policy Across the SADC Region*, in *Overcoming Barriers to Climate Change Adaptation Implementation in Southern Africa*, Africa Institute of South Africa, Pretoria, South Africa, 2012.

[96] C. P. Mubaya, J. Njuki, E. P. Mutsvangwa, F. T. Mugabe, and D. Nanja, "Climate variability and change or multiple stressors? Farmer perceptions regarding threats to livelihoods in Zimbabwe and Zambia," *Journal of Environmental Management*, 2012.

[97] A. Braimoh, *Climate Smart Agriculture: Lessons from Africa for the World*, 2018. [Online]. Available: https://medium.com/world-of-opportunity/climate-smart-agriculture-lessons-from-africa-for-the-world-ef05e2786b3f. [Accessed: 10-Mar-2024].

[98] M. Madzwamuse, *Climate Governance in Africa—Adaptation Strategies and Institutions: A Synthesis Report*, 2010. [Online]. Available: https://za.boell.org/sites/default/files/climategovernancehandbook.pdf. [Accessed: 12-Apr-2024].

[99] M. Giordano and E. Bassini, *Climate Change and Africa's Future*, 2019. [Online]. Available: https://www.hoover.org/research/climate-change-and-africas-future. [Accessed: 29-Mar-2024].

[100] S. Elia, *All About Deserts: The Desert Biome*, 2019. [Online]. Available: https://ucmp.berkeley.edu/exhibits/biomes/deserts.php. [Accessed: 13-Mar-2024].

[101] J. Hance, *How the Sahara Keeps the Amazon Rainforest Going*, 2015. [Online]. Available: https://news.mongabay.com/2015/03/how-the-sahara-keeps-the-amazon-rainforest-going/. [Accessed: 12-Mar-2024].

[102] I. Valodia and J. Taylor, *COP27 Key Outcomes: Progress on Compensation for Developing Countries but More Needed on Climate Justice and Equity*, 2022. [Online]. Available: https://theconversation.com/cop27-key-outcomes-progress-on-compensation-for-developing-countries-but-more-needed-on-climate-justice-and-equity-195017. [Accessed: 11-Apr-2024].

[103] W. Okocha, *What Is COP and Can It Save the Planet?*, 2022. [Online]. Available: https://mw.linkedin.com/posts/linkedin-news-africa_what-is-cop-and-can-it-save-the-planet-activity-6995375415682891776-vRiw. [Accessed: 12-Mar-2024].

# Nano Bionic Effect of Multiwall Carbon Nanotubes (MWCNT) and Graphene Oxides (GO) for Climate Resilient Horticultural Plants: A Strategy for Ensuring Food Security

Jadala Shankaraswamy

Department of Fruit Science, College of Horticulture, Mojerla, Sri Konda Laxman Telangana Horticultural University, Wanaparthy-509382, Telangana, India

Received:- 01 October 2025/ Revised:- 06 October 2025/ Accepted:- 16 October 2025/ Published: 31-10-2025
Copyright @ 2025 International Journal of Environmental and Agriculture Research
This is an Open-Access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (https://creativecommons.org/licenses/by-nc/4.0) which permits unrestricted Non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

***Abstract—*** *Climate change presents some real hurdles for horticultural crops and its becoming clear that unseasonal temps, like warmer days in winter, water scarcity in summer, wild weather during cropping season especially flower bud differentiation and unseasonal rainfall creating huge crop loss. Now, there's evidence that Integrated Farming Management (IFM) techniques can actually help lessen the bad impacts and still align with current horticultural policies. IFM ensures horticultural practices are more resilient when faced with these climatic changes but in more environmental problems, using new materials like multiwall carbon nanotubes, graphene oxide, and hydrogen rich water (HRW) in horticultural could really help plants handle climate change better. Because the world's population is growing and the environment is getting worse, we need farming methods that don't harm the environment and can lessen the effects of pollution. These cool nanomaterials have impressive physical qualities, like being super strong and conducting electricity well, which can help plants grow better and withstand stress. Also, recent research in college of horticulture mojerla, Sri Konda Laxman Telangana Horticultural University on Ramanathapuram Gundu Malli (Jasminum sambac Ait.) shows that improved crop adaptability when it is introduced from Ramanathapuram, Tamil Nadu to Horticultural Instructional Farm, Madanapuram, Telangana and also shown extra abilities in increasing plant height, promotion of number of primary, secondary and tertiary branches, imparted good quality flower attributes and overall performance in changed climate*.

***Keywords— Multi-wall carbon nanotubes, hydrogen-rich water, graphene oxide, climate, resilience.***

## I. INTRODUCTION

Severe impacts of climate change on horticultural crops requires the implementation of effective resilience strategies to strengthen horticultural crops and their vegetative phenology. Developing climate -resilient crops through traditional crop breeding is slow and costly process and time consuming but implementing multiwall carbon nanotube and graphene oxides techniques as it entails high efficient, simple to use by farmers and target alteration to make resilient crops to changed climatic condition. Presently, the effect of crop root on crop root zone and thermal characteristics are poorly understood, and new fertilizers are rarely considered as remedy. College of Horticulture, Mojerla, Sri Konda Laxman Telangana Horticultural University explored the effect of applying multiwall carbon nano tube (MWCNT), Graphene oxide (GO), Hydrogen rich water hold significant potential for improving cultivar Ramanathapuram Gundu Malli (*Jasminum sambac* Ait.) and enhancing resilience to changed environment and abiotic stresses (Shankaraswamy et al., 2023). MWCNT surface charges may stimulate the production of water channel protein thus improving the plants water transport absorption. From the investigation two types nano inputs (MWCNT, GO) were directly uptake and translocated to roots, stems, and leaves at concentration of 10-50 mg/L that indicates that MWCNT, GO, enhance growth parameter and flower production under dwindling resources. Hydrogen rich water of 1000 ppb proved effective in freshness index of jasmine flowers while reducing the physiological loss of water. According to the several studies revealed that MWCNTs could be an alternative for control of pathogens due to activation of antioxidant defence system in plants by increasing the ascorbic acid, flavonoids content, and the glutathione peroxidase enzyme. Hence, application of MWCNT, GO, Hydrogen rich water (HRW) are promising strategy and found to be alternative to breeding approaches in plants to anticipate, prepare for, respond to, and recover from the impacts climate change, while

maintaining their essential functions and adapting to new conditions. Therefore, exogenous application of MWCNT, GO, HRW are holistic and multidimensional approach that combines efforts to adapt to unavoidable changes and mitigate future warming to ensure food security in a changing climate.

## II. MULTIWALL CARBON NANOTUBE

### 2.1 Physical properties of MWCNTs:

Nanotechnology is quick progress has unlocked fresh possibilities for boosting horticulture's ability to bounce back from climate change. Of all the nanomaterials out there, multiwall carbon nanotubes, or MWCNTs, have really caught researchers' eyes. This is thanks to some awesome physical traits they have, like being super strong, conducting heat really well, and having great electrical properties. Because of these traits, MWCNTs are looking like a strong contender for use in growing plants that can handle climate change better. They can help plants get nutrients more effectively and also boost how well they deal with stress. We from college of horticulture, mojerla, Sri Konda Laxman Telangana Horticultural University are putting more and more weight on doing things sustainably these days, so we really need to use new materials that can soften the blow of environmental problems, especially when it comes to not having enough water and the soil getting worse. Our studies on effect of MWCNT on Ramanathapuram gundumalli (*Jasminum sambac* Ait ) showing extra abilities in increased plant height, promotion of number of primary, secondary and tertiary branches, with more plant spread as well as superior flower growth attributes denoted that MWCNTs can work even better in in horticulture crops (Shankaraswamy et al., 2023). So, really getting to grips with what MWCNTs can do and how we can fit them into farming systems is super important if we want to encourage horticulture that can keep going strong even as the climate changes.

MWCNTs, or multiwall carbon nanotubes, possess physical traits that really make them promising for use in horticulture designed to hold up against climate change. Think about it: They're super strong, and conduct electricity and heat remarkably well, which means they could make agricultural materials more stable and effective. Plus, their large surface area lets them soak up a lot of stuff, which is great for cleaning up polluted water – a growing problem thanks to climate change (Reale et al., 2023) and get this: the way they're structured lets them mix easily with other materials. This leads to new composite materials that are stronger and handle heat better. This could be a big deal for making protective coatings or even improving soil, helping plants survive tough conditions and supporting sustainable farming. So, grasping these characteristics is key to using MWCNTs in forward-thinking horticulture farming approaches.

### 2.2 Mechanical and electrical properties that enhance plant growth and resilience:

Multiwall carbon nanotubes, or MWCNTs, have mechanical and electrical properties that can really help plants grow and handle climate change better. These nanotubes are known for being strong yet flexible, which means they can make plant tissues stronger too. This extra strength helps plants deal with tough conditions like not enough water or really hot weather. Plus, MWCNTs can conduct electricity, and this can help roots absorb nutrients and water more effectively, leading to healthier and more productive plants overall. It's especially useful when we create nanocomposite materials that go into the soil or coat the plants, making it easier for essential resources to get where they need to go. By using these properties, scientists can come up with new ways to farm sustainably and tackle the problems caused by our changing climate (Dincer et al., 2024).

### 2.3 Use of MWCNTs in soil enhancement and nutrient delivery systems for climate-resilient crops:

Climate change's persistent problems demand find new ways to do horticulture, especially when it comes to making soil healthier and getting nutrients to horticultural plants so crops can survive. Multiwall carbon nanotubes (MWCNTs) are proving to be a good answer, as they help improve soil and how well plants absorb nutrients. It's largely because of how MWCNTs are made that they can improve soil aeration, keep water in the soil, and hold onto nutrients-all really important for helping plants grow when the weather is not cooperating. Putting MWCNTs into soil improvement plans can also boost how easily plants can use the necessary nutrients, helping plants stay healthy and produce more. Studies lately have been pointing out how MWCNTs help turn on plant defences, which then makes them better at handling stress and still produce a good amount even when climate change is causing problems. This mix of nanotechnology and farming doesn't just back sustainable methods, but it fits right in with needing environmentally friendly new ideas in growing food, pushing us toward a more tough horticultural cropping system (Shankaraswamy and Thirupathi, 2022). By preliminary research with MWCNTs and Graphene oxides and Hydrogen rich water revealed strength of these nano-material to accelerate physiological and molecular level adaptation under shifting atmospheric conditions.

### 2.4 Significance in Horticultural Crops:

Multiwall carbon nanotubes, or MWCNTs, have become quite important in nanotechnology, drawing attention for how they might be used in today's farming practices. What makes them special is their design, which features several layers of graphene sheets rolled into cylinders; because of this structure, MWCNTs have impressive mechanical, electrical, and thermal characteristics that can help plants withstand climate change. These nanotubes can assist plants to grow better even when the environment is tough by making it easier for nutrients and water to reach them. This addresses important problems related to having enough food and maintaining farming for the long term. It seems that these nanotubes might also be good at soaking up contaminants from water used in agriculture, which is getting more and more important because of environmental damage and a lack of resources. Furthermore, there's evidence that MWCNTs might make soil better and help plants stay healthy, opening up a wide array of possibilities that could drastically change how farming is done to cope with climate change.

## III. GRAPHENE OXIDE (GO)

The integration of graphene oxide into horticultural practices offers a potentially significant step forward in bolstering plant production against climate change effects. With global climate shifts creating substantial obstacles for conventional horticulture, the need for creative solutions to maintain food availability and long-term viability is clear. Graphene oxide, with its notable physical attributes, such as considerable mechanical robustness, thermal resilience, and impressive electrical conductivity, appears well-suited for enhancing both plant health and development. It can improve absorption of nutrients and also act as a shield against environmental pressures to plants. Additionally, the well-considered use of organic fertilizers has been shown to help revitalize soil and lessen climate change's adverse effects on how much crops produce (Kakura I et al.). This intersection of materials science with horticultural practices might just transform how we approach farming that can withstand climate-related challenges. In the same line experiment was conducted in order to see the Effectiveness of GO on Jasmine phenology and climatic adoptability when introduced from Ramanathapuram to Horticulture Instructional farm, Madanapuram, college of horticulture, Mojerla, Sri Konda Laxman Telangana Horticultural University. From results it was evident that graphene oxide had a positive impact on shelf life of flower. It could be as result of reestablishment of redox homeostasis in flower (Thirupathi et al., 2022).

### 3.1 Overview of Graphene Oxide and its significance in modern science:

Graphene oxide, or GO, has really grabbed the interest of scientists lately because it's so useful and has some pretty amazing properties. It's basically a single layer of carbon atoms arranged in a honeycomb pattern. Because of this structure, GO is super strong, conducts electricity well, and has a large surface area. This makes it an exciting material for lots of different uses. What's neat is that we can change its properties to fit specific needs, particularly when it comes to helping plants withstand climate change. GO can help soil hold onto water and deliver nutrients more effectively, potentially making crops more resilient to environmental challenges, which is important given our changing climate. Plus, GO's ability to have a significant impact in several fields, from health to sustainability, shows just how vital it is to pushing science forward (Engineering C et al.). Support for research, like funding from Shell Global Solutions UK, shows how important it is to invest in GO research for future innovations (Ajovalasit et al.).

### 3.2 Physical Properties of Graphene Oxide:

Graphene oxide's characteristics really matter when we think about how it can be used, especially for helping plants handle climate change. Its surface is really big, about 2630 $m^2/g$, which helps it connect with living things easily, so plants can grab nutrients better. Plus, the oxygen stuff in it helps it dissolve in water, making it simple to use on farms. Because it's both strong and light, it makes things like plant containers last longer. Also, it might help soil and plants conduct electricity better, which can help plants grow and stay strong when things get tough. Because of this, it's super important to study how GO can store energy, which ties into making farming more sustainable.

### 3.3 Unique structural characteristics and their implications for material performance:

Graphene oxide (GO) has some pretty neat features, like a large surface area, chemistry that can be tweaked, and impressive mechanical strength. Because of these qualities, GO is uniquely suited to tackle some of today's farming problems related to our changing climate. Its properties don't just make GO perform well in different uses; they also lead to fresh ideas in climate-smart agriculture. For instance, it can make nutrient delivery systems that work well and protect crops, boosting both crop resilience and how much we can grow, as noted in (Giannini et al.). In addition to that, GO affects soil and the tiny organisms that live there, greatly improving how sustainable our farming is. It helps soil hold onto nutrients, all while trying not to mess

with the environment too much. These developments show how important new materials, like graphene oxide, are in encouraging sustainable farming methods. These methods can fight the bad effects of climate change and, ultimately, help horticulture industry to make enough food to cater the needs of growing populations.

### 3.4 Applications of Graphene Oxide in Horticulture:

Graphene oxide (GO) shows considerable promise when integrated into horticulture. Consider its potential to improve climate resilience specifically in plant production. GO's physical properties—it has exceptional strength and a high surface area and allow it to effectively deliver nutrients. That delivery significantly increases how much of the essential elements plants can actually use. Climate change presents major obstacles to horticultural crops productivity, so the use of climate-smart horticultural strategies including innovative uses for graphene oxide is very important for reducing negative impacts on yield and soil health (Munaweera et al., 2023). Ultimately, graphene oxide's multifunctionality makes it an important part of the push for more sustainable horticultural technologies and practices.

### 3.5 Role of graphene oxide in enhancing plant growth and resilience to climate stressors:

Generally speaking, incorporating graphene oxide (GO) into horticulture shows promise for improving plant growth and helping plants withstand climate-related stresses. GO has some interesting physical characteristics, like a large surface area and good conductivity, which can help plants take up nutrients and encourage root growth. This better nutrient absorption is really important for plants dealing with abiotic stressors such as drought and salinity, where it's often harder for them to get the nutrients they need. Research suggests that GO can boost plant metabolism, leading to increased photosynthetic efficiency and biomass production – both crucial for maintaining horticultural output in tough conditions. Plus, GO's ability to create a protective layer around plant roots can improve stress tolerance, lessening the harm from extreme environmental conditions. As climate change continues to threaten our food supply, using graphene oxide might be an innovative approach to strengthen plant resilience, potentially making it a key element in sustainable farming practices.

## IV. HYDROGEN RICH WATER (HRW)

The horticultural sector's need for resilience, especially given climate change, has spurred interest in hydrogen-rich water (HRW). This particular water, containing extra hydrogen molecules, might help plants grow faster and handle drought conditions better. Cities are starting to use clean energy, as noted in initiatives like (Cleveland et al.), to combat climate and environmental issues. Therefore, it is crucial to look at sustainable methods in horticulture, too. We can see how HRW affects plant health in studies that show how it helps plants thrive in different environments, similar to how forests recover as described in (Abella et al., 2027). This all leads to a detailed look at what HRW is made of and how it could help horticultural crops to withstand climate change.

### 4.1 Overview of Hydrogen Rich Water (HRW) and its significance in Horticulture:

In the realm of horticulture, Hydrogen Rich Water (HRW) has become quite important because it may help plants better handle climate change. HRW, which has a lot of dissolved hydrogen in it, is thought to give plants protection from oxidative stress. Because of this, plants grow healthier and produce more, which is really important as the environment changes more and more. It seems that using HRW can make crops hold onto water better and take in nutrients more effectively, which are very important for farming practices that are good for the environment and follow the United Nations Sustainable Development Goals (SDGs). Also, because people are paying more attention to farming that doesn't harm the environment, HRW is being looked at as a good way to deal with the money and environmental problems that modern horticulture faces. So, it's really important to understand how HRW can help plants grow in a way that can withstand climate change.

### 4.2 Physical Properties of Hydrogen Rich Water:

Looking into what makes hydrogen-rich water (HRW) special shows us some interesting things about how it could help plants handle tough climate conditions. HRW seems to dissolve things better and has less surface tension than regular water. This might mean plants can soak up nutrients and water more easily. Because it's more permeable, plants could grow better and be tougher when things get stressful, like during a drought. On top of that, some studies hint that the antioxidants in HRW could fight off oxidative stress in plants, helping them grow in a healthier way. If we use these HRW qualities in farming, we might not only get more crops, but also manage our resources more sustainably. As cities try to grow food in a way that matches climate goals, really understanding how HRW and plants work together is key. This can help us find more sustainable ways to produce food, which fits in with plans like the ones talked about in (Cleveland et al., 2019).

### 4.3 Chemical composition and unique characteristics of HRW:

Hydrogen-rich water, or HRW, mainly features dissolved hydrogen (H2) gas, and this is what gives it its potential to help plants grow and become more resilient. Because it has a high concentration of molecular hydrogen, it can act as a useful antioxidant, reducing oxidative stress in plants, which is quite important for horticulture that can withstand climate change. HRW also appears to help plants absorb nutrients better by improving how their roots work, helping them hold onto water in the soil, which then leads to higher crop yields. It's also worth noting that HRW can affect different physiological processes in plants, like photosynthesis and metabolism, so it plays a significant role in horticultural practices that are sustainable and given the growing need for new solutions to deal with climate change, it's increasingly important to grasp the chemical composition and properties of HRW for creating robust strategies that boost plant production.

### 4.4 Applications of HRW in Climate Resilient Plant Production:

The rising relevance of plant production that is climate-resilient has spurred the investigation of creative answers, one being Hydrogen Rich Water (HRW). It's worth mentioning that HRW displays physical characteristics unlike any other, properties that boost a plant's ability to deal with stress, as well as encourage growth, and improve overall crop quality when conditions are tough. It serves as a key tool in farming that is sustainable. Studies, for example, propose that when HRW is used, the germination rates of seeds can be increased significantly, and it can encourage root development, a factor that is critically important for plants dealing with drought and soils that don't have enough nutrients. This kind of resilience is especially pertinent, considering that horticultural practices have to adjust to climate change's looming impacts. Moreover, bringing HRW into crop management strategies can support broader environmental goals. This includes a decreased reliance on fertilizers that are chemical and improved water use efficiency, aligning it with circular resource management principles as mentioned in current literature on sustainable farming practices (Cleveland et al., 2019).

### 4.5 Impact of HRW on plant growth and stress resistance:

The use of Hydrogen Rich Water (HRW) in horticulture to boost plant growth and resistance to stress has been getting some notice lately. HRW might actually make things like photosynthesis and nutrient absorption work better, which could mean bigger harvests when things get tough. It seems to help them deal with drought and not having enough nutrients, which makes them stronger overall. It's also been noted from our research that HRW can protect against oxidative stress and decreased the post-harvest deterioration and senescence during storage by modulating the antioxidant defence system in Jasmine flowers (Shankaraswamy, 2023). HRW is becoming pretty important for building farming systems that can withstand climate change because it helps plants deal with tough environmental issues. By increasing intercellular $H_2$ Synthesis by lowering the incidence of rot, limiting the intensity of reproduction, lowering the amount of lipid peroxidation and enhancing superoxide dismutase activity (Shankaraswamy and Thirupathi, 2022).

## V. CONCLUSION

Integrating multiwall carbon nanotubes, graphene oxide, and hydrogen-rich water shows a remarkable possibility for improving horticultural methods that withstand climate change. These high-tech materials not only boost the overall physical health of plants but also greatly strengthen their ability to resist climate-related stress. Putting MWCNTs and Graphene oxides and Hydrogen rich water to work in horticultural crops production can bounce back from climate change looks like a real step in horticulture. Combining insights from material science and horticulture might just lead to major advances in making crops more resilient in tough conditions. This kind of comprehensive research approach should be encouraged in production practices of horticultural system. Future studies should probably concentrate on refining how we make and use MWCNTs, graphene oxide, HRW to customize its characteristics for different horticultural crops situations.

## ACKNOWLEDGMENT

I am extremely grateful to Dr. Girwani for providing moral support

## CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

## REFERENCES

[1] Thirupathi G, Shankaraswamy J, Prashanth P, Sathish G (2023). Studies on effect of carbon based nanomaterial, novel plant growth promoting agents on growth of jasmine (*Jasminum sambac* Ait.). *Pharma Innovation*., 12(1): 401-404.
DOI: 10.22271/tpi.2023.v12.i1e.18031.

[2] Reale, Anna (2023). Functionalized carbon nanotubes as adsorbents for wastewater remediation.

[3] Shankaraswamy, J. and Thirupathi, G. Plant bionic effect of carbon based nano material on growth, yield, quality, and shelf life of jasmine ( Jasminum sambac) Cv. Ramanathapuram. Ppaer presented at : NSHCHT 2022. Proceedings of National Symposium on horticultural crops of humid tropics for nutritional and livelihood security; 2022 Dec 2-3; Kodagu, Karnataka, India.

[4] Dinçer, İbrahim, Karabuğa, Arif, Utlu, Zafer, Yüksel (2024). 15th International Exergy, energy and environment symposium (IEEES-15)". İstanbul Atlas Üniversitesi.

[5] I.V. Kakura, V.V. Stankevich, A.I. Kostenko, O.M. Fedorishina (2024). "Advantages of using organic fertilizers to restore the fertility of war-damaged soils". Hygiene of Populated Places.

[6] Thirupathi, G. (2022). Effect of Carbon Based Nanomaterial, Sodium Hydrosulfide (NaHS) and Hydrogen Rich Water on Growth, Yield, Quality and Shelf life of Jasmine (Jasminum Sambac Ait.) Cv. Ramanathapuram Gundumalli (Unpublished Master's thesis), College of horticulture, Mojerla, Sri Konda Laxman Telangana Horticultural University, Telangana, India.

[7] Abella, Scott R, Farrish, Kenneth W, Oswald, Brian P., Shaw-Faulkner (2017). Effects of Ponderosa Pine Ecological Restoration on Forest Soils and Understory Vegetation in Northern Arizona. SFA Scholar works, 2017, https://core.ac.uk/download/84705501.pdf.

[8] Cleveland, Cutler J., Fox-Penner, Peter, Pollack, Adam, Walsh (2019). "Carbon Free Boston: Energy Technical Report.

[9] Malka Munaweera, Madhavi de Silva, Nilwala Kottegoda, Nimshi Fernando, Sayani Nimanka (2023). Climate Smart Agriculture: The Role of Fertilizer Innovations and Efficient Plant Nutrient Management". University of Sri Jayewardenepura.

# Coffee and Tribal Communities in Wayanad: Historical, Socio-Economic, and Environmental Dimensions

Krishna Chandana

Independent Researcher, Agriculture, WAYANAD, INDIA
*Corresponding Author

Received:- 01 October 2025/ Revised:- 14 October 2025/ Accepted:- 20 October 2025/ Published: 31-10-2025
Copyright @ 2025 International Journal of Environmental and Agriculture Research
This is an Open-Access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (https://creativecommons.org/licenses/by-nc/4.0) which permits unrestricted Non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

***Abstract*****—** *Coffee cultivation in Wayanad, Kerala, constitutes a unique study in the interrelations among ecology, culture, and livelihood sustainability. This socio-environmental study intends to explore the indigenous art of tribal coffee cultivation in Sugandhagiri by the Paniya, Kurichiya, and Adiya tribes. Tribal coffee cultivation and trade have been historically influenced by colonial plantation systems, ecological transformations, and current global value chains. Synthesis of the literature and field-based perspectives in this study is used to illustrate the socio-economic value of shade-grown coffee, agroforestry measures for biodiversity conservation, and the threats posed by climate change. This research uses a mixed-methodology approach combining historical analysis, agronomic studies, and socio-economic surveys. The results show that tribal farmers have maintained biodiversity conservation through organic and shade-based systems but face problems due to price volatility, climate threats, and institutional neglect. Policy-level interventions like the Fairtrade, GI certification, and community-based conservation initiatives are reviewed. The study, therefore, concludes that indigenous Wayanad coffee practices sustain tribal livelihoods and build ecological resilience but need systemic support to ensure their future.*

***Keywords— Wayanad, tribal coffee, indigenous farming, shade cultivation, sustainability, livelihoods.***

## I. INTRODUCTION

The district of Wayanad, situated to the north of Kerala, bears a geography, biodiversity, and socio-cultural fabric dominated by tribal communities. Among the various crops grown in this place, coffee holds a place of prominence not merely as a commercial product but also as a cultural and ecological practice that sustains tribal livelihoods. The Sugandhagiri part of Wayanad is emblematic of this relationship, where traditional methods of shade-grown coffee cultivation have been maintained for generations. These systems are characterized by agroforestry with native shade trees, organic inputs, and traditional ecological knowledge intertwined with tribal systems.

Coffee was introduced into Wayanad in the plantation era, during the 19th century, under the British regime [1]. The colonial government promoted the coffee plantations as commercial entities, greater-further alienating tribal lands while disrupting their subsistence farming. Recognizing the estates to provide income opportunities only for the outsider settlers and European planters, the indigenous communities were denied access to these lands, outcast as wage-laborers, or displaced to lesser fertile tracts of forested land [1]. Despite these intricacies, the tribal people gradually embraced coffee in their farming systems and began intercropping it with their traditional crops and forest resources. With the passage of time, growing coffee gradually became the only few working opportunities for the tribal households, a trend that continues today.

Coffee cultivation in Sugandhagiri presently corresponds largely to family types of cultivation, with most families cultivating less than two hectares of land. Generally, under this type of land cultivation, they practice shade-growing systems where coffee plants are interspersed with native tree species, spices such as pepper and cardamom, and fruit trees such as jackfruit and bananas [3]. This agroforestry system serves important ecological functions: it maintains biodiversity corridors, conserved soil moisture, and served as a habitat for pollinators and provide other ecosystem services [4]. Studies of carbon sequestration reveal that shade coffee farms in India, Wayanad being one such area, sequester carbon in large amounts when compared with monoculture systems and thus positioned tribal coffee as an example of climate-smart agriculture [4].

Economically advanced, coffee gardens are the mainstay of tribals in Wayanad. Cash incomes earned through coffee cultivation provide for basic food security, education, and health care for the families. As coffee is sold on highly volatile international markets, economic sustainability has always been difficult. This trend has taken an extreme toll on smallholders across the country—including the tribal communities of Wayanad—resulting in debt, distress migration, and widespread livelihood distress. Although some kind of relief has been provided in bad times by cooperative societies and the government, the tribal farmers are still economically vulnerable, a situation further worsened by their incapacity to access credits as well as markets and extension services.

Other environmental stressors add to the trials faced by tribal coffee cultivators. The climate variability in Wayanad has brought about unusual rains, extended dry spells, and additional pest and disease occurrences such as the coffee berry borer and leaf rust [8], [9]. For a small-scale farmer whose resources may not permit him or her to practice any technological or chemical technique, such climatic and ecological stresses might only add to the threat of crop failure. Recent research highlights climate changes as a long-term existential threat to coffee production in Wayanad and endorses the set-up of adaptive measures like diversified cropping, shade management, and the adoption of resilient coffee varieties [10], [11].

Despite these vulnerabilities, tribal coffee cultivation exudes resilience born from the lore of traditional ecology. Indigenous farming methods typically embrace low-input organic farming, mulching, mixed cropping, and shade management techniques that do not jeopardize the natural order. These mechanisms not only lessen the cost overheads of production but also fall into the global framework of sustainable and ethical coffee [12]. Moreover, community-based conservation movements, for example, one involving the M.S. Swaminathan Research Foundation, have indicated the possibility of strengthening both environmental and livelihood outcomes by integrating indigenous farming practices with biodiversity conservation [13].

Market-oriented innovations like Fairtrade certification and GI labeling provide a new option to possibly upgrade the socio-economic condition of tribal farmers. Fairtrade mechanisms have benefited tribal communities of coffee growers by enhancing household incomes, strengthening farmer organizations, and reducing their vulnerability to price shocks [5]. Similarly, the GI certification of "Wayanad Coffee" would help in further distinguishing its product in niche markets for premium prices and in support of collective branding initiatives [14], [15]. However, these mechanisms generally call for institutional support and capacity-building-their very two things that remain scarce in tribal areas.

The worth of Sugandhagiri coffee, however, far surpasses economic value and lies over broader expanses of environmental and cultural fields. Local coffee gardens form a sort of a socio-ecological landscape wherein biodiversity, climate resilience, and cultural identity intermingle. On the other hand, for such a system to survive, structural issues need to be intervened, which consist of market exclusion, climatic risks, and the sidelining of tribal voices in agricultural-policy discourse.

The present paper proposes to document and analyze the art of indigenous coffee cultivation in Sugandhagiri, highlighted by its socio-cultural grounds, ecological services, and current threats. Thus, synthesizing historical, socio-economic, and environmental standpoints would, in turn, help place the tribal coffee cultivation in Wayanad as a case for sustainable agroforestry-based livelihood improvement and rural livelihood resilience.

## II. LITERATURE REVIEW

### 2.1 Colonial Roots and Historical Context:

Saravanan [1] stresses the colonial-era introduction of coffee to Wayanad was more than mere agricultural development; it was, in fact, a drastic disturbing socio-ecological transformation. The coffee plantations exploded in growth under British rule, culminating in grave instances of land alienation among indigenous Paniya, Kurichiya, and other tribal groups. The tribes, who once indulged in shifting cultivation and community-controlled agriculture, were now displaced and had their own relationship with land and forest restructuring. Mathew [2] stresses further that the plantation economy worked to alter the ecology of Wayanad by establishing monocultures as opposed to native agroecological practices. Nevertheless, though the colonial plantations were exploitative in nature, tribal groups gradually incorporated coffee into their mixed farming systems, alongside pepper, areca nut, and subsistence crops. This is perhaps one of the few documented instances of a cultural negotiation process whereby an externally introduced crop was localized into the rhythms of tribal life.

Mathew also notes 2 that because of the colonial land tenure system, socio-economic inequalities were exacerbated and that the tribal communities were prevented from exercising land ownership rights. While ranchers and settlers benefitted from the

profitability of coffee, the tribal families had to become laborers on lands they formerly claimed to work freely. But eventually, native integration of coffee with shade-based agroforestry systems did mitigate some of the ecological disturbances brought by monocultural plantations. Coffee was, and still is, a cultural landscape element in the western Ghats and signifies both colonial indigestion and indigenous resistance. From a historical perspective, it is thus very important to understand how Sugandhagiri plantations operate today, which somehow carry connotations of being both colonial and livelihood dependent.

### 2.2 Socio-Economic Dimensions:

George and Krishnaprasad [3] suggest that coffee serves as the main cash crop for the tribal farmers of Wayanad, yet its extra-economic role is riddled with contradictions. On the one hand, coffee sales have supported the livelihood of many household expenses such as education and health care. On the other, farmers have remained vulnerable to externalities of price fluctuation in global markets. Price crashes, most spectacularly reported in late 1990s and early 2000s, have subsequently plagued many smallholders with cycles of indebtedness, hence forcing borrowers to rely on moneylenders or cooperative loans. The authors emphasize that this duality of income versus vulnerability marks the socio-economic relationship between tribes and coffee cultivation.

Jena and Grote [4] continue the discussion by looking further into the role of certification schemes with Fair Trade and organic coffee initiatives inside. Their research shows that participation in certification programs has the potential to increase the bargaining power of farmers, their access to markets, and their household income. But on the path to certification there are costs and compliance requirements that not all tribal farmers are able to sustain. Besides, benefits become unevenly distributed as resource-rich farmers, with an easier time meeting standards, capture them to the disadvantage of a marginal tribal farmer. Hence, certification while promising does not outrightly resolve structural vulnerabilities posed by integration into the global coffee market.

George and Krishnaprasad [3] further argue that farmers rely heavily on middlemen or traders, often reducing their share in the final market value of coffee. Although couriers do exist in Wayanad, not all tribal households have access at times, and participation seems to be very variable. Thus, the socio-economic implications of coffee cultivation should be observed through both the income lens and that of power relations in markets, land rights, and institutional support. From this standpoint, coffee is a sort of opportunity and a dependency simultaneously, urging the necessity of an intervention that would shield tribal households from economic shocks.

### 2.3 Agroforestry and Environmental Sustainability:

Anil Kumar et al. [5] states that shade-grown coffee systems in Wayanad are considered to be among the world-renowned examples of native agroforestry systems. Unlike sun-grown coffee monocultures, these systems allow for more than one canopy layer and maintain a variety of tree species, birds, and insects. This kind of ecological complexity is favorable for biodiversity conservation, soil fertility, and water retention thereby making the system climate-stress-resilient. The authors also mention how coffee agroforestry can serve as a carbon sink, making Wayanad's tribal coffee-growing systems agents of climate change mitigation. At once, this illustrates that such systems help sustain human livelihoods while also assuming ecological roles, which testifies to the intrinsic sustainability of indigenous practices.

Sivarama et al. [6] discuss the topic of increasing interest in organic coffee cultivation in Wayanad. Their study elaborates that an organic system, being a system less dependent on chemicals, ideally rests on traditional ecological knowledge; and is beneficial to the soil. The study also puts forth the difficulties faced by people in tribal areas in obtaining certification and marketing of the product-it is an area of concern as they become barriers in organic-locus for people classified as in need of poverty relief. NGOs and various cooperatives attempted to work around these problems; however, many problems lie at the systemic level, especially the scaling up of organic coffee without compromising indigenous autonomy.

According to Anil Kumar et al. [5], the tradition of maintaining sacred groves and protecting shade trees is complementary to the conservation of biodiversity in the coffee systems. Many tribal farmers regard coffee not simply as a crop but as something associated with forest protection and ritual practices within a wider ecological web. The cultural perspective thus distinguishes Wayanad’s coffee from commercial plantation models, where sustainability is considered within an ecological-social matrix. An acknowledgment of such systems in global sustainability narratives affirms the need to protect tribal agroforestry practices from the homogenizing impact of markets.

### 2.4 Soil, Pests, and Climatic Vulnerabilities:

#### 2.4.1 Soil Fertility and Nutrient Imbalances:

Soil fertility in Wayanad's coffee plantations may have been undergoing degradation through the process of depletion and imbalance, a condition often blamed on continuous monocropping and inadequate replenishment of soil nutrients, as seen from the research of Prasad et al. [7]. The coffee plant is very demanding of nitrogen, potassium, and phosphorus, but smallholder farmers usually do not have available either organic or chemical fertilizers in quantities needed. This has resulted in reduced yield over a period, diminished quality of beans, and higher proneness to attacks from pests and diseases. Adding to the woes of fertility is the sloping nature of Wayanad terrain, which results in heavy topsoil erosion during monsoon rains. All studies on tropical soil systems confirm that fertility loss in direct measure affects the long-term sustainment of crops, thus embedding a vicious cycle of reduced income of farmers from declining yields that in turn prohibits them from investing further in soil management.

#### 2.4.2 Pest Incidence and Coffee Berry Borer:

Pest infestations are especially important in agronomic spheres. The main pest has, in fact, been identified as the coffee berry borer (*Hypothenemus hampei)* for Arabica in India. According to Jayakumar et al. [8], infestation levels in Wayanad are reported to reach above 20% in cherries during peak outbreak periods, causing severe economic losses. The pest causes lower yields to be inaccurate in quality appraisal since the beans affected are refused when sold on the market. Any kind of conventional pest control, notably through endosulfan, was once possible in the region but now faces a ban as it goes against the environment and environmental safety. Previous regulations, thus, have become problematic for local farmers in their search for cheap and effective means of pest handling. Nevertheless, these IPM measures; for instance, biological control using parasitoids, fungal biocontrol agents, and cultural actions such as shade management, have been slowly introduced to all small-scale tribal growers, but their uptake is uneven.

#### 2.4.3 Climatic Variability and Production Risks:

Climatic factors accentuate the dynamics of pests and vulnerabilities of the soil. Kumar and Srinath [9] report that erratic rainfall patterns, extended dry spells, and sudden shifts in temperature have disrupted the traditional coffee calendar in Wayanad. Flowering, highly dependent on the timing and strength of pre-monsoon showers, is becoming highly irregular, resulting in asynchronous fruiting and harvesting schedules. Any irregularities result in a lower output and increased costs on manual labor. Another synergistic effect of moisture stress and warming has enabled the further proliferation of secondary pests and fungal pathogens-the leaf rust. This variability increases another layer of risk for the tribal farmers who have poor irrigation facilities and limited finances; they are therefore already precarious in their livelihoods.

### 2.5 Certification and Market Enhancement:

#### 2.5.1 Fairtrade Certification and Income Stabilization:

Certification was thereby promoted and has been considered one possible way of income stabilization of small producers of coffee. Radhika et al. [10] argue that Fairtrade certification guarantees a minimum price and gives the seller access to a select international market that appreciates ethical sourcing. Hence, in a way, for tribal farmers of Wayanad such schemes serve as a buffer to protect against the fluctuating global prices of coffee, which are very often below their costs of production. Certification also works as an incentive for environmental conservation in terms of shade growth of coffee and lesser use of synthetic chemicals, which presents a good complement with existing agroforestry traditions in the region. However, involvement in the scheme demands high organizational efficacy in record keeping and compliance with monitoring standards, something that many tribal cooperatives find difficult to maintain.

#### 2.5.2 Geographical Indication (GI) Tagging:

Wayanad coffee has been identified to have GI status, which is an important brand-building instrument. Rathour et al. [11] observe that a GI name works to enhance the reputation of a product due to its unique geographical origin, terroir, and cultural heritage. Wayanad coffee's geographical indication is strengthened by its growing in mixed agroforestry, its distinctive flavor characteristics, and the involvement of the indigenous community in its cultivation, marketing, and export in both domestic and global markets. Lalitha and Vinayan [12] further feel that GI tagging can really help position Wayanad coffee just as well as premium varieties such as those from Colombia and Ethiopia are positioned in the global market. Yet, according to empirical

evidence, the largest benefits of GI are only gained by a small set of growers, excluding smallholders who usually do not have access to export channels and remain dependent on intermediaries who capture a large portion of the value addition itself.

### 2.5.3 Challenges in Implementation:

Nevertheless, the promise of certification and GI mechanisms is challenged by implementation problems. Most tribal farmers lack the literacy and organizational base to face certification audits. Cooperative societies act as intermediaries but weak institutional capacity limits their efficiency. Even the higher prices promised by Fairtrade and GI systems are not being realized in practice, given concerns over global oversupply, property competition, and discrepancies in quality. The consequence has been a discouragement among farmers who put their faith in certification at one time but have seen very little financial gains from it. Hence, these strategies for market enhancement theoretically offer a way to enhance the livelihood of the farmer, yet the impact they have in practice is inconsistent.

## 2.6 Tribal Livelihoods and Cultural Perspectives:

### 2.6.1 Coffee and Tribal Identity:

Growing coffee in Wayanad is intricately interwoven with tribal livelihood and identity. Joy [13] states that for various indigenous communities, coffee is not merely a cash crop but also a cultural asset related to pride and heritage of the community. Coffee is grown on ancestral land and integrated into traditional agroforestry systems that support biodiversity. Coffee holds a symbolic meaning beyond its economic returns, in that it influences how intergenerational knowledge is transmitted, social rituals established, and bonds formed. For instance, in community festivals, coffee cherries may be gifted, thereby strengthening the status of coffee in the local identity.

### 2.6.2 Gendered Dimensions of Coffee Labor:

Geetha Nath [14], the gender-based division of labor plays a great role in the dynamics of coffee production in tribal households. Among these, women of the Adiya community are involved in weeding, harvesting, drying, and post-harvest processing. Balakrishnan and Anilkumar [15] state that much of the time, while women contribute to coffee production, they seldom participate in decision-making processes related to land ownership, marketing, and cooperative leadership. Economic insecurity is precipitated, and women are further denied access to training or certification programs. Some have suggested gender-sensitive initiatives such as women's cooperatives or microfinance programs as a countermeasure toward these inequities.

### 2.6.3 Coffee as a Livelihood Anchor:

From beyond identity and gender, coffee also remains the livelihood mainstay for the tribal communities of Wayanad. For many families, it constitutes most of the annual cash income, which is used to pay for their children's education, medical care, as well as the household necessities. On the other hand, the cultivation of only one crop makes farmers vulnerable to market fluctuations, a sudden outbreak of pests, or a direct change in climate. This has given rise to and sustained a paradox whereby coffee serves to nurture the tribal livelihoods and yet traps them in a cycle of vulnerabilities. Diversification-oriented interventions like intercropping with spices, fruits, or even beekeeping have been successful to some extent but are limited in scope.

# III. METHODOLOGY

The research design is a mixed one, consisting of secondary data analysis, case study evaluation, and comparative synthesis, providing a comprehensive understanding of the history, socio-economic significance, and ecological sustainability of tribal coffee farming in Wayanad, with special emphasis on the tribal coffee farms of Sugandhagiri.

## 3.1 Secondary Data Collection:

The first step involves a systematic review of literature that encompasses historical accounts, socio-economic analyses, plus ecological assessments pertaining to coffee cultivation in Wayanad. Sources are considered from peer-reviewed journals, government reports, NGO documents, and extension publications. Special consideration is directed toward works that elucidate the colonial origins of plantation economies, tribal displacement, and avenues for adaptation. Socio-economic studies that focus on income dynamics, price volatility, and indebtedness of tribal farmers are analyzed within the broader livelihood frameworks to understand where coffee farming fits. Concurrently, ecological studies around shade-growing systems, biodiversity conservation, carbon sequestration, and organic farming initiatives are studied for the environmental sustainability dimension. This secondary data review forms the basis for triangulating past and present realities of tribal coffee farming.

**FIGURE 1: Geographical Map of Tribal Coffee Farming**

### 3.2 Case Study: Sugandhagiri Tribal Coffee Farms:

The second component of the methodology involves a further in-depth case analysis of Sugandhagiri tribal coffee farms in Wayanad. Literature recognizes Sugandhagiri as a major site for tribal-group-led initiatives in coffee growing, usually in support from cooperatives, NGOs, and state agencies. Data strands for such analyses are taken from published reports, extension documents, and secondary case studies about the cooperative structure, nature of farming, trend in yields, and socio-economic impact on tribal households in general. This case-study approach grounds the broader theoretical insights in a localized context, highlighting the lived experiences of the tribal farmers, the difficulties they face in terms of market access, and the solutions they are looking at for ecological resilience. Special reference is made to tribal women's involvement in coffee farming and how the gendered division of labor affects household income and food security. The Sugandhagiri case meeting highlighted the challenges of cooperative functioning and the collective efforts of tribal farmers to sustain coffee production. It also reflected tensions between institutional support and ground-level realities.

**FIGURE 2: Farmers' Discussion during the Sugandhagiri Case Meeting**

### 3.3 Comparative Framework: Tribal Practices vs. Global Models

The study further sets up a comparative framework to situate Wayanad tribal coffee practices vis-à-vis such global certification and market enhancement models as Fairtrade, organic certification, and Geographical Indication (GI) tagging. The comparative exercise looks at how far tribal farmers could possibly benefit from global market mechanisms and what barriers they face from the fragmentation of small holders, from certification costs, and from market dependencies. The study thus relates the Wayanad strategy to the global scene and tries to further the understanding of both potentialities and difficulties associated with certification based on livelihood enhancement.

## IV. RESULTS

This study states that the Wayanad tribal coffee landscape has a multi-dimensional and opposing role from the ecological and socio-economic perspective.

First and foremost, the shade coffee systems of Wayanad are ecologically beneficial to the ideologies of biodiversity conservation and carbon sequestration. Findings suggest that these traditional agroforestry systems support the continued existence of tree species diversity, serve as a habitat for birds and insects, and contribute to ecosystem services to a great extent [1]. Studies have indicated that carbon stored under shade-grown coffee systems is on par or in some cases more than that stored in any other managed agricultural systems, thus providing Wayanad's tribal coffee landscapes a powerful premise in terms of climate mitigation [1]. This ecological resilience brings an additional value proposition from the point of view of sustainable certification.

From a socio-economic standpoint, for tribal households, coffee stands as the prime cash crop, mainly among the Paniya, Adiya, and Kuruma communities. However, putting all the weight on a single commodity exposes farmers to price fluctuations. Past records indicate that international coffee prices fluctuating alongside local debt cycles have typically caused the very households from which dependency is sought to plunge into economic precarity [2]. The lack of strong institutional frameworks, coupled with the inability to access formal credit institutions, further aggravates this vulnerability. Coffee would be the tribe's livelihood during favorable price cycles; ironically, its overdependence has subjected tribal farmers to financial insecurity.

Organic cultivation is a common method in the tribal farms of Wayanad and is most often guided by traditional low-input farming methods. The commercial monoculture plantations, in contrast, use chemical inputs to enhance productivity, while tribal systems generally rely on natural composting, shade-grown diversity, and fewer external inputs. Evidence from the field reveals that organic methods help increase soil fertility and maintain ecological integrity but result in low production outputs compared to intensive systems [3]. This, therefore, creates a trade-off between ecological sustainability and income maximization, with farmers sometimes forced to choose between short-term returns and long-term soil health and cultural values of farming.

In brief, this establishes a double narrative: The tribal coffee systems of Wayanad render strong ecological benefits yet face slumping cultural resilience, whereas these systems, conversely, are starker economically through market vagaries and climatic threats. Certifications and associations might be a way out, but structural backing is a must to achieve real livelihood betterment.

## V. DISCUSSION

The present study suggest the twin roles of tribal coffee production in Wayanad: as an ecological safeguard and an economic lifeline for livelihood. Shade-grown coffee at Sugandhagiri triggered ample ecosystem services for biodiversity conservation and carbon sequestration, paralleling global confirmations on agroforestry systems [1]. These ecological grounds show that coffee cultivation in the tribal landscape is more than just an economic value and has an environmental public good character. However, the very sustainability of the system is now assaulted by forces so sheer as those posed by the markets and climate change.

Agricultural dependence on coffee exposes tribal households to economic vulnerabilities, especially with ever-fluctuating global coffee prices. Just like any smallholders all over the world, tribal farmers of Wayanad suffer from income fluctuations that often end up in debt, driving them to approach informal credit sources for rescue [2]. These financial insecurities reduce the ability that these farmers have to take risks in new innovations and respond to ecological hazards. Organic growth in most tribal farming realms speaks volumes about these farmers' affinity towards sustainable methods; however, reduced yields compared to conventional systems continue to cull their economic viability [3]. This trade-off becomes an aching chasm in the realm of policy where livelihood shall not be sacrificed for ecological sustainability.

Climate vulnerabilities add to the problems. Expected alterations in rainfall patterns and anticipated escalations in the pest populations, including coffee berry borer, reflect the concerns faced throughout tropical coffee zones [4], [5]. These threats only increase the precarity of tribal coffee systems, which need adaptive measures such as mixed cropping, soil fertility maintenance, and water conservation. Though tribal farmers have practiced mixed cropping in the past, due to the swift course of climate change, it has become imperative to strengthen institutional arrangements and facilitate investment in climate-resilient technologies.

Certification schemes such as Fair Trade and Geographical Indication labeling might support tribal coffee producers in stabilizing incomes and recognizing the cultural identity of tribal coffee. Some evidence from other contexts indicates that Fairtrade certification may have a positive effect on household incomes and market access [6]. However, Fairtrade certification is still rarely adopted in Wayanad by tribal farmers because of the heavy costs for compliance, lack of organizational capacities, and inequitable sharing of benefits [7]. Thus, GI certification coupled with tribal branding may further enhance niche market positioning, yet demands the integration of policy, marketing infrastructure, and cooperative engagement.

All in all, this means that tribal coffee cultivation can sustain ecological and cultural values, though it is battered by economic fragility and climate risk. To strengthen resilience, multi-scale interventions must be considered, mixing certification incentives, institutional credit access, and climate-smart agronomic practices. Future considerations must ensure that all attempts at sustainability include tribal people in the decision-making process, so that sustainability measures reflect their cultural identity and livelihood aspirations.

## VI. CONCLUSION

In Wayanad and in Sugandhagiri, for instance, the investigation of tribal coffee cultivation shows that it is more than a livelihood activity-it is an integrated socio-ecological activity that maintains biodiversity, sustains environmental resilience, and preserves cultural heritage. Hence, in a nutshell, the shade-grown, organic-oriented systems practiced by the tribal communities are indeed the best examples of sustainable agroforestry on a worldwide scale-interspersing and conferring ecological value to these landscapes. However, with environmental benefits come worsening livelihood security conditions of tribal households, affected by erratic coffee prices, diminished yields in organic systems, and scarce institutional support.

The findings ended up showing that climate change constitutes a serious challenge faced in ensuring that tribal coffee cultivation remains a feasible entity in the limelight. Rainfall variations, pest incidences, and soil degradation all are threats to the ecological balance on which this system exists. Yet, apart from the traditional diversified cropping systems that build tolerance for the system, further measures need to be introduced, such as climate-smart agricultural practices, soil conservation, and water management to cushion against future uncertainties.

In conclusion, tribal coffee cultivation in Wayanad embodies a unique intersection of ecology, economy, and culture. Hence, any interventions for its sustainability must aim with a fine balance between environmental considerations and livelihood support. Strengthening institutional back-up, climate resilience, and market integration via certification and branding would allow tribal farmers to retain their legacy while enhancing their socio-economic condition. With dual focus, hence, the future promises an enduring state of tribal coffee both as a livelihood system and as a sustainable agriculture model at the global level.

## REFERENCES

[1] P. R. Jena and U. Grote, "Fairtrade certification and livelihood impacts on small-scale coffee producers in a tribal community of India," *Applied Economic Perspectives and Policy*, vol. 39, no. 1, pp. 87–110, 2017.

[2] V. Saravanan, "Colonialism and coffee plantations: Decline of environment and tribals in Madras Presidency during the nineteenth century," *Indian Economic & Social History Review*, vol. 41, no. 4, pp. 465–488, 2004.

[3] C. H. I. T. T. A. P. U. L. I. S. Kumar, "Economic analysis of coffee cultivation and it's impact on socio-economic conditions of tribal farmers in Visakhapatnam District of Andhra Pradesh," Ph.D. dissertation, Acharya N. G. Ranga Agricultural Univ., Hyderabad, India, 2017.

[4] S. Ambinakudige, "The global coffee crisis and Indian farmers: The livelihood vulnerability of smallholders," *Canadian Journal of Development Studies/Revue canadienne d'études du développement*, vol. 28, no. 3–4, pp. 553–566, 2009.

[5] P. Prasad, N. Hariyappa, N. Chandrashekar, G. Manonmani, S. Hareesh, S. Nadaf, … & K. Sujatha, "Studies on soil fertility status of coffee growing regions in Wayanad district," *Journal of Plantation Crops*, vol. 46, no. 3, pp. 180–189, 2018.

[6] A. C. Anjitha, M. Hema, A. Prema, D. Franco, and S. Jan, "Battling climatic shifts: Vulnerability of coffee-based farm households and resilient practices in coffee farms, Wayanad, Kerala," *Indian Journal of Agricultural Economics*, vol. 79, no. 3, pp. 420–429, 2024.

[7] N. P. Anil Kumar, A. I. K. Saleem Khan, and V. Balakrishnan, "Coffee, climate and biodiversity: Understanding the carbon stocks of the shade coffee production system of India," in *Handbook of Climate Change and Biodiversity*, Cham: Springer Int. Publishing, 2018, pp. 113–134.

[8] V. M. Byrareddy, J. Kath, L. Kouadio, S. Mushtaq, and V. Geethalakshmi, "Assessing scale-dependency of climate risks in coffee-based agroforestry systems," *Scientific Reports*, vol. 14, no. 1, p. 8028, 2024.

[9] G. T. Sivarama, N. Hariyappa, M. Selvakumar, and K. V. Mohanan, "Organic farming in Wayanad–a preliminary analysis," in *Proc. XIII Swadesi Science Congress*, 2003, pp. 16–22.

[10] C. V. Joy, *Small Coffee Growers of Sulthan Bathery, Wayanad*. Kerala Research Programme on Local Level Development, Centre for Development Studies, 2004.

[11] A. C. Anjitha, M. Hema, A. Prema, D. Franco, and S. Jan, "Battling climatic shifts: Vulnerability of coffee-based farm households and resilient practices in coffee farms, Wayanad, Kerala," *Indian Journal of Agricultural Economics*, vol. 79, no. 3, pp. 420–429, 2024. (duplicate of [6], keep only once in final list if required)

[12] M. Jayakumar, C. K. Vijayalakshmi, P. A. Rahiman, and M. Rajavel, "Weather based forewarning models for coffee berry borer and shot hole borer in Wayanad, Kerala," *Mausam*, vol. 67, no. 4, pp. 879–886, 2016.

[13] A. M. Radhika, K. J. Thomas, and R. K. Raju, "Geographical indications as a strategy for market enhancement—lessons from rice GIs in Kerala," *The Journal of World Intellectual Property*, vol. 24, no. 3–4, pp. 221–236, 2021.

[14] T. P. Rathour, A. Kumari, M. R. Chandana, V. V. Varaprasad, and N. K. Tulluru, "GI certification of plantation crops for doubling farmer's income in India," 2023. [Online]. Available: https://www.researchgate.net/profile/Tp-Rathour/publication/373213793

[15] N. Lalitha and S. Vinayan, "GIs for protecting agro-biodiversity and promoting rural livelihoods: Status, strategies and way forward," Gujarat Inst. of Development Research, Ahmedabad, Working Paper 240, 2017.

[16] A. Sundar, "Geographical indications as a tool for sustainable growth: An analysis in the backdrop of Kerala's agricultural products in the European Union market," *Agricultural Economics Research Review*, vol. 28, no. 1, pp. 67–78, 2025.

[17] J. Mathew, "Plantation economy in colonial Malabar—with special reference to Wayanad," in *Proc. Indian History Congress*, vol. 67, pp. 730–737, 2006.

[18] G. Nath, "Socio-technical system analysis of tribal and settler farmers in the western ghat regions of Wayanad district in Kerala," Ph.D. dissertation, Kerala Agricultural Univ., Vellayani, India, 2007.

[19] D. Balakrishnan and A. Anilkumar, "Gender analysis of 'Adiya' tribal agricultural labourers of Wayanad district," M.Sc. thesis, Kerala Agricultural Univ., Thrissur, India, 2017.

[20] D. Kumar and P. Srinath, "Climate trends in Wayanad: Voices from the community," SSRN Working Paper, 2014.

[21] J. George and P. Krishnaprasad, "Agrarian distress and farmers' suicides in the tribal District of Wayanad," *Social Scientist*, vol. 34, no. 7/8, pp. 70–85, 2006.

[22] R. Ramakrishnan, S. Rajendrakumar, and N. K. Kothurkar, "Regional sustainability of the Kattunayakan tribe in Kerala, India through the enhancement of agricultural, livestock, and livelihood options," *Agricultural Systems*, vol. 217, p. 103929, 2024.

[23] N. Prathapachandran and V. Devadas, "Sustainable and traditional agricultural practices to reinforce income dynamics among tribal communities in rural Wayanad, Kerala, India," *Agricultural & Rural Studies*, vol. 1, no. 3, pp. 0017–0017, 2023.

# Development and Evaluation of Vegetable and Fish Wastes Silage (VFWS) Additive to Nile Tilapia (*Oreochromis niloticus*) Feeds

Fenny A. Alleluya[1]; Antonio J. Barroga[2*]; Luzviminda S. Quitos[3]; Criselda P. Francisco[4]; Redel L. Gutierrez[5]

[1,3,4,5]Department of Environmental Science and Meteorology, College of Science, Central Luzon State University, Science City of Munoz, Nueva Ecija, Philippines
[*2]Department of Animal Science, College of Agriculture, Central Luzon State University, Science City of Munoz, Nueva Ecija, Philippines
*Corresponding Author

Received:- 01 October 2025/ Revised:- 10 October 2025/ Accepted:- 19 October 2025/ Published: 31-10-2025
Copyright @ 2025 International Journal of Environmental and Agriculture Research
This is an Open-Access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (https://creativecommons.org/licenses/by-nc/4.0) which permits unrestricted Non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

***Abstract—*** *Nile tilapia fingerlings fed varying levels of vegetable and fish waste silage (VFWS), following a completely randomized design (CRD) were studied to determine the optimum level of replacement to the commercial diet on growth parameters, and economic benefits. In the experiment, a total of 120 fingerlings with an initial mean weight of 8.89 g were used. They were divided into four (4) groups based on their dietary needs: Treatment 1 (T1) was the pure commercial feeds, 100% CF; Treatment 2 (T2) 10% VFWS and 90% CF; Treatment 3 (T3) 15% VFWS and 85% CF; and Treatment 4 (T4) 20% VFWS and 80% CF with three (3) replications each. The results showed that there were no significant differences between any of the treatments in terms of growth parameters indicating comparable performance of the treated diets with the control. Moreover, T3 has the tendency to increase the survival rate, which suggests an apparent acceptability of the VFWS. Finally, the results proved a promising utilization of VFWS as a replacement of commercial aqua diets for Nile Tilapia fingerlings at the early growth stage.*

***Keywords— Vegetable fish waste silage; feed utilization; growth; fish meal; Nile tilapia.***

## I. INTRODUCTION

Fish, particularly tilapia, is a staple food in Filipino cuisine. It is the primary source of dietary protein, vitamins, micronutrients, and minerals (Pandey and Upadhyay, 2022). Not only do they provide essential proteins but are also a valuable commodity traded worldwide and serve as a means of income for fish-producing countries, including the Philippines. Besides producing a large quantity of fish, aquaculture operations also help alleviate food insecurity, a major issue among the country's poorest regions and agricultural households.

A record of 214 MT was produced globally in fisheries and aquaculture in 2020, including 178 MT of fish and 36 MT of algae (SOFIA, 2022). This growth largely accounts for the advancement of aquaculture within Asia. Much of aquaculture's success depends on feed quality and availability. Good quality feed, however, tends to be more expensive, partly because some feed ingredients used are imported, which increases production costs whether it is for poultry, swine, or aquaculture. Around 60-70% of the entire cost of operating a fish farm is spent on feed (Mukta, Khan, Mian & Juice, 2019). One way to reduce feed costs in fish farming is by utilizing alternative feed ingredients. These can include waste materials that are readily available. Fish waste and vegetable wastes, in particular, have the potential to be used as raw material for producing feed additives, thereby decreasing reliance on imported feed ingredients.

Likewise, the aquaculture industry's growth is often accompanied by a significant volume of waste, if not properly managed it can lead to environmental pollution and loss of biodiversity. Fish waste is generated in large quantities from processing plants and wet markets. The average daily production of fish waste in Philippine wet markets was found to be 70.3 kg, with no significant differences across locations (De Ungria et al., 2023). However, vegetable wastes, on the other hand, account for 40 to 50% of postharvest losses of fruits and vegetables and 42% of its vegetable production losses was due to spoiling, resulting in landfill problems (Sanchez et al., 2019). Despite this, the vegetable waste is a rich source of nutrients. It contains between 2.11% and 2.71% protein, 1.08% fat, and 14- 15% fiber. It also has a high-water content, ranging from 89% to 90% which is a good source of calcium and other minerals (Andriani & Pratama, 2022).

Somehow, these kinds of waste materials can be processed and further enhanced through fermentation. This process increases the bioavailability of nutrients, improves the palatability of the feed. Fermenting vegetable and fish waste is expected to improve the quality of feed additives, increase digestibility, and develop flavors and aromas suitable for fish (Adriani, Lili, Zidni, Wiyatna, & Risiana., 2020). Feed additives are substances added to animal feed to enhance its nutritional value, improve the animal health and productivity, or make the feed more appealing (Olagunju et al., 2023). Nutrition is known to have a considerable effect on the reproductive performance and gonadal development of fish (Gioacchini, Olivotto, Ashouri, & Carnevali., 2023). The addition of feed additives was found to improve growth but the nutritional impact of reducing the protein digestibility and amino acid balance in this feed heavily affected the overall performance, particularly feed conversion ratio (FCR) and survival rate (Towers, 2015).

Including this fermented vegetable and fish waste silage into tilapia feeds provides for a more sustainable and profitable aquaculture sector. This aligns with the principles of circular economy, which minimizes waste and reuses resources. Some studies have explored the use of single waste materials, but the combination of assorted vegetable leftovers and fish viscera waste and its optimal inclusion levels as supplementary fish feed additives has not yet been thoroughly investigated. Finding ways for sustainable feed production is essential particularly cost saving strategies considering the unabated increase of the price of commercial aqua diets. Therefore, the utilization of vegetable and fish viscera wastes when processed by fermentation procedures to make it safe and palatable for inclusion to commercial aqua diets is very timely. Finally, these nutritional strategies can further mitigate the adverse effect of climate change at the same time addressing economic problems of the fisherfolks in the country.

Fermentation improves the nutritional content and may also positively influence fish growth, health, and overall production efficiency. This study developed a sustainable, cost-effective, and environmentally responsible feed additive using fermented dietary vegetable-fish waste silage additive into Nile tilapia feeds. Additionally, incorporating waste products aligns with circular economy principles and sustainable aquaculture. The findings could benefit the fisherfolks, as it enhanced their understanding of alternative feed sources and their practical applications to improve the nutritional quality and palatability of the feed, resulting in better growth, feed conversion ratio, making fish farming more efficient and reduced overall feed costs.

The study focused on developing and analyzing the nutritional composition of fermented dietary vegetable and fish waste silage (VFWS) as a potential feed additive for Nile tilapia. It evaluated the effectiveness of silage-based feeds on the growth performance, feed conversion ratios and weight gain. Additionally, the study examined the economic benefits of using VFWS compared to traditional feed additives. However the study was limited to a specific period, which might have restricted the understanding of long-term effects of silage-based feeds on Nile tilapia. Some of the parameters, such water quality parameters were not analyzed due to the limitation of resources, time, and situation.

## II. METHODOLOGY

### 2.1 Study Area:

The study was conducted at Central Luzon State University (CLSU), which is situated on a 658-hectare land in Science City of Muñoz, Nueva Ecija, Philippines. Specifically, the research area was located at the CLSU BINHI Conservation Park. The campus location is identified by coordinates 15.7327°N latitude and 120.9310°E longitude, and it stands approximately 79 meters

above sea level. The campus is surrounded by rice fields, orchards, and features several bodies of water such as ponds, and streams.

**FIGURE 1: Aerial image of CLSU BINHI Conservation Park. (Source: Google Earth Pro; Photo was taken by Fenny Aleluya)**

### 2.2 Experimental Set-up and Units:

The study utilized twelve aquaria to simulate feeding trials for Nile tilapia (*Oreochromis niloticus*) fingerlings. Each aquarium was a half-cylinder made from a 200- liter plastic barrel drum, measuring 58 x 58 x 91 cm. The aquaria had maintained an equal amount of water at a depth of 29 cm. Before the experiment, all aquariums underwent thorough cleaning using a water-soluble degreaser for disinfection, thus preventing fish mortality. The 120 Nile tilapia (*Oreochromis niloticus*) fingerlings used in the study were obtained from the Bureau of Fisheries and Aquatic Resources-National Freshwater Technology Center (BFAR-NFTC), CLSU Compound, Science City of Muñoz, Nueva Ecija. A total of one hundred twenty (120) Nile tilapia fingerlings with a mean initial weight of 8.89 g were used in the experiment and were allocated in four dietary treatments with ten (10) fingerlings per replicate and conditioned for one week before the feeding trial began. Throughout the week, they were fed commercial fry mash.

### 2.3 Preparation of Vegetable and Fish Waste Silage:

Vegetable wastes such as leaves stems, and/ peels were collected from New Market inside the CLSU Campus. The visceral organs of any fish (e.g., liver, spleen, and intestines) were collected from the wet market in Science City of Muñoz, Nueva Ecija. These materials were thoroughly washed with clean water to remove dirt and minced into small pieces using an electronic shredder. The shredded vegetable and fish wastes were mixed in a ratio of 1:1 (w/w) by weight. The mixture was mixed with 24 g of an odor-erasing composting microbial powder premix per 3 kg vegetable and fish waste silage (VFWS). The commercial powder premix contains beneficial microorganisms, and nitrogen-fixing bacteria, that facilitate the fermentation process. The mixture was transferred to a 3.5-liter plastic container for 14 days in a dry, cool place. The vegetable and fish waste silage were stirred 3 times a day from day 1-7 and twice a day from day 8-14. After fermentation, the fermented silage was mixed with the commercial aqua diets at varying replacement levels and considered as formulated treated diets.

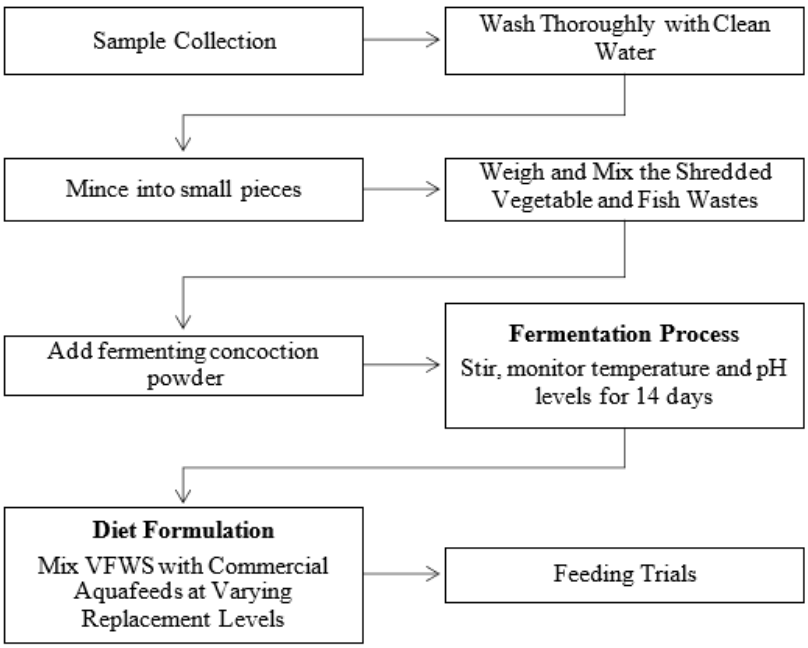



**Figure 2: Flowchart diagram on the development of the fermented dietary VFWS to Nile tilapia (Barroga, 2000; Anizah et al., 2021)**

### 2.4 Treatment Assignments:

The study followed a completely randomized design with four (4) dietary treatments, each with three (3) replicates. The treatments consisted of three (3) different levels of VFWS inclusion in the diet: Treatment I (100% Commercial Feeds) with a 26% crude protein level, Treatment II (10% Vegetable and Fish Waste Silage + 90% Commercial Feeds), Treatment III (15% Vegetable and Fish Waste Silage + 85% Commercial Feeds), and Treatment IV (20% Vegetable and Fish Waste Silage + 80% Commercial Feeds). The VFWS was mixed manually and thoroughly with the commercial surfer pre-starter mash and was prepared every three (3) days to ensure its freshness. A three-day (3) adjustment period was observed to establish palatability, acceptability and voluntary feed intake of the fish.

### 2.5 Proximate Analysis:

The complete proximate analysis of the experimental diets was done in the Feed Chemical Analysis Laboratory, Regional Field Office III, City of San Fernando, Pampanga. Results were standardized as percentage on a dry matter basis for accurate comparison. Methods included oven-drying for moisture content, the Kjeldahl method for crude protein analysis, furnace-ignition for ash, and ANKOM$^{TM}$ filter bag technology for crude fat and crude fiber measurements.

### 2.6 Feeding Guide and Management Procedure:

The fingerlings were fed three (3) times a day at 9:00 a.m., 12:00 p.m., and 4:00 p.m. for 30 days. The amount of feed given was 5% of their body weight. The initial and final body weights of the fish were recorded before and after the feeding trials commenced. Dead fish were monitored daily, and the feeding rate was adjusted based on the growth and behavior of the fish. The aquaria were cleaned daily by siphoning water and excess feed with a 4-mm diameter plastic tube. Half of the water volume was replaced every day, and the attached algae in the aquaria were removed every two days.

### 2.7 Growth Performance Parameters:

After the 30$^{th}$ day of feeding trials, the growth parameters of the Nile tilapia fingerlings were analyzed. The specific growth rate (SGR), feed conversion ratio (FCR), survival rate (SR), and absolute growth rate (AGR) were determined and calculated using the following formula (Campang and Vera Cruz, 2018).

$$SGR = \frac{lnWF - lnWo}{tf - to} \times 100 \quad (1)$$

Where:

lnWf = natural log of final weight

lnWo = natural log of initial weight

tf = final time in days

to = initial time in days

$$FCR = \frac{Total\ feed\ consumed\ (g)}{Total\ weight\ gain\ (g)} \times 100 \quad (2)$$

$$SR\ (\%) = (\frac{Sf}{So}) \times 100 \quad (3)$$

Where:

Sf = total number of fingerlings survived So = total number of fingerlings stocked

$$AGR = \frac{WF-Wo}{t} \quad (4)$$

where:

Wf = final weight

Wo = initial weight

t = number of days

### 2.8 Statistical Analysis:

Data on feed conversion ratio, specific growth rate, absolute growth rate, and survival rate were statistically tabulated and analyzed using One-way ANOVA for Completely Randomized Design (CRD). STAR software version 2.0.1 was used to compare the treatment means using the Tukey HSD test.

## III. RESULTS AND DISCUSSION

### 3.1 Description and Characteristics of Vegetable and Fish Waste Silage:

The physical properties of silage such as odor, color, and appearance, are commonly used to determine if the silage is suitable to feed Nile tilapia fingerlings. Over the 14-day fermentation period, the vegetable and fish waste silage were assessed based on these parameters. Initially, from Day 1 to Day 5, the silage emitted a very strong and offensive fishy odor due to the rapid breakdown of fish proteins and fats. During this phase, the VFWS had a wet and heterogeneous mixture of chopped vegetable and fish viscera, presenting a slurry-like consistency with varied colors contribute by the different components of the raw materials used. By Day 6, the fermented VFWS produced oil, visible on its surface, a result of the continuous breakdown of fish fats. The presence of proteins and oils from the fish can make the silage sticky to the touch. However, the unpleasant odor became less offensive from day 6, and the appearance became more consistent as the components further decomposed. The color started to become more uniform, indicating ongoing fermentation process. From Day 7 to Day 14 the fermented VFWS became odorless. By Day 14, the silage had transformed into a semi-liquid with a uniform dark brown color due to the oxidation of organic matter and the mixing of different vegetable and fish components. These changes demonstrate the effectiveness of the fermentation process in stabilizing and homogenizing the waste materials, resulting in an odorless product suitable as feed additive to Nile tilapia.

### 3.2 14-Day pH Measurements:

Figure 3 shows the pH levels of fermented vegetable and fish waste silage over 14 days, with a standard pH of 6 as reference. Initially, the pH drops quickly from 4.9 on day 1 to 4.5 by day 3, indicating that the fermentation process effectively lowers the pH, although not into the optimal range of 2-4. Over the following days, the pH fluctuates slightly between 4.5 to 5.2, but consistently stays below 6, demonstrating ongoing acid production and effective preservation. From day 9 onwards, the pH stabilizes between 4.5 and 4.9, indicating a stable phase of fermentation with balanced acid production and consumption. Maintaining a lower pH, ideally between 2 and 4, is crucial for silage. This lower pH range inhibits the growth of pathogens and spoilage organisms, ensuring the silage safe and stable over time (Libonatti, Agüería, & Breccia., 2023). Additionally, the acidic environment helps preserve the nutritional value of the silage by slowing down the degradation processes. The fermentation process, driven by lactic acid bacteria converting sugars into lactic acid, effectively reduces the pH and indicates successful preservation efforts.

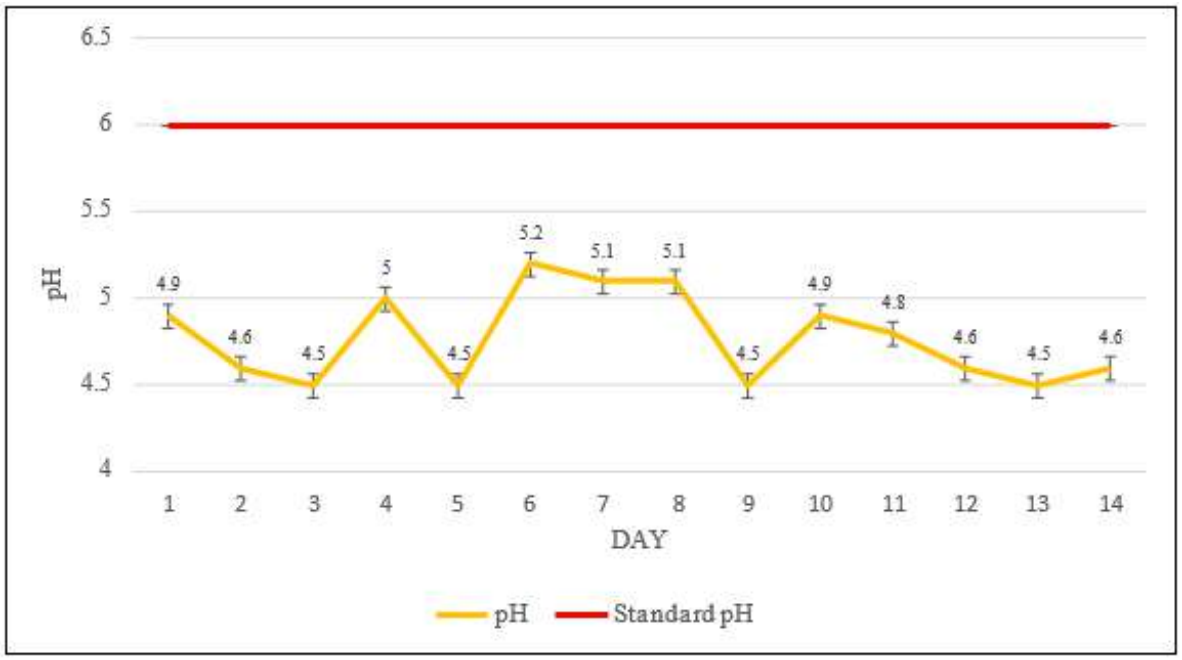



**FIGURE 3: Mean pH levels of fermented VFWS for two (2) weeks**

### 3.3 14-Day Temperature Measurements:

The 14-day temperature observation of fermented vegetable and fish waste silage shows in figure 4. Initially, at 26°C on Day 1, temperatures remain within the optimal range for silage fermentation. Notable increase in temperature on Day 5,6, and 9 to 28.3°C, 28.6°C, and 30.6°C, respectively, may have accelerated fermentation, promoting faster acidification and nutrient preservation. This conform with the study of Li et al. (2019), the temperature during ensiling is approximately 28°C particularly in tropical areas. Despite minor decrease in temperature on Day 4, 7 and 11, the overall temperature range remains acceptable to efficient fermentation suggest an effective process, preserving the nutritional integrity of the silage throughout the observation period. The temperature in the present study agreed with the observation of Peñarubia (2020) who recommended of 25°C to 40°C for ideal fermentation environment.

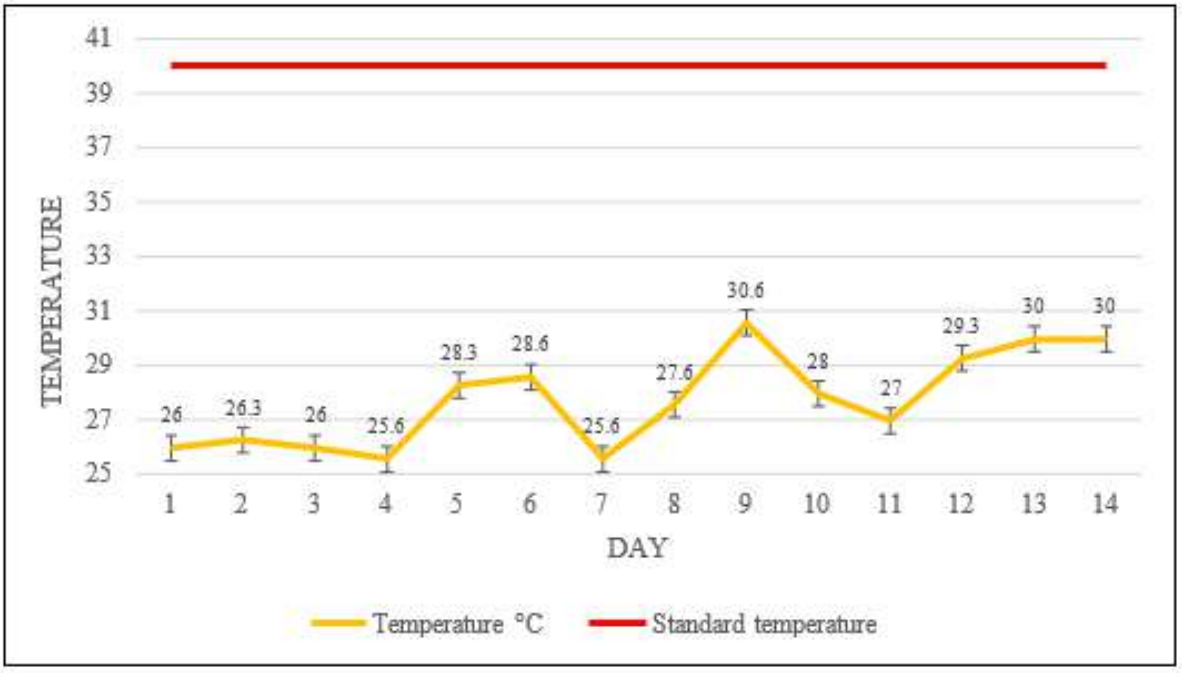



**FIGURE 4: Mean temperature levels of fermented VFWS for two (2) weeks**

### 3.4 Chemical Composition of Experimental Diets:

**TABLE 1**

**COMPARATIVE CHEMICAL ANALYSIS OF THE TREATMENT DIETS, % DM**

| Parameter | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Treatment** | **CF (%)** | **VFWS (%)** | **Crude Protein** | **Crude Fat** | **Crude Fiber** | **Ash** | **Moisture** |
| I | 100 | 0 | 26.5 ± 0.3 | 6.3 ± 0.4 | 7.3 ± 0.9 | 12.8 ± 0.5 | 8.3 ± 0.1 |
| II | 90 | 10 | 23.8 ± 0.8 | 5.8 ± 0.7 | 6.6 ± 0.6 | 12.2 ± 0.1 | 14.1 ± 0.3 |
| III | 85 | 15 | 21.1 ± 0.1 | 6.0 ± 0.6 | 6.1 ± 0.3 | 11. 4 ± 0.3 | 19.2 ± 0.9 |
| IV | 80 | 20 | 20.9 ± 0.6 | 5.5 ± 0.7 | 6.0 ± 0.9 | 11.4 ± 0.5 | 20.3 ± 0.5 |

The comparative analysis of the different treatment diets and its corresponding parameters: crude protein, crude fat, ash, and moisture was shown in Table 1. Treatment I, representing the control group (100% Commercial Feeds), exhibits the highest levels of crude fiber (7.3%) and crude protein (26.5%), while the introduction of vegetable and fish waste silage (VFWS) in Treatments II, III, and IV results in a gradual decrease in both parameters. Interestingly, the inclusion of VFWS leads to an increase in ash content across treatments, suggesting a higher mineral content in the substrate. Moreover, moisture content shows a consistent increase with the addition of VFWS, indicating its higher moisture content compared to the original feed. It is interesting to note that while there was a decreasing nutrient content as replacement level by VFWS increases to 20%, a comparable growth rate and tendency to increase in survival rate was still evident when a feeding trial was done to Tilapia during their early growth stage. This suggest that there might be valuable nutrients present in the VFWS which served as an offsetting effect on possible nutrients that were sacrificed from the commercial diet.

### 3.5 Growth Performance of Nile tilapia:

#### 3.5.1 Survival Rate:

**TABLE 2**

**SURVIVAL RATE OF NILE TILAPIA FINGERLINGS FED WITH VARYING LEVELS OF VFWS AFTER 30-DAYS OF FEEDING**

| Treatment | Survival Rate (%) | | | Mean (± SE) |
|---|---|---|---|---|
| | R1 | R2 | R3 | |
| I | 80 | 80 | 50 | 70± 10.00$^{ns}$ |
| II | 60 | 100 | 40 | 66.67± 17.64$^{ns}$ |
| III | 80 | 90 | 70 | 80± 5.77$^{ns}$ |
| IV | 50 | 60 | 70 | 60± 5.77$^{ns}$ |
| *P-value* | | | | 0.6436$^{ns}$ |

$^{*}$Significant at P<0.05

$^{ns}$ Not significant

Table 2 shows the average survival rates for each of the different treatments. Across treatments, there was no statistically significant difference (P>0.05) in the mean survival rates. With a mean value of 80%, Treatment III had the highest percentage survival rate, indicating that the amount of silage incorporated in this treatment was most favorable for the fingerlings. TI (Control) and TII had comparable survival rates with a mean value of 70% and 66.67%, respectively, suggesting these silage levels were similarly effective. Treatment IV had the lowest survival rate with a mean value of 60%, which might imply that the silage incorporation level in this treatment was less optimal for the survival of fingerlings.

These findings conform with Asefa, Melaku & Tsige (2021) that incorporating fish silage into the diets of Nile tilapia fries has no significant difference in terms of survival rate with 83.3%, which confirm the viability of fish waste silage as a sustainable feed additive that promotes growth and survival without compromising feed efficiency, indicate that a 20% inclusion of fish silage is ideal for early-stage Nile tilapia.

### 3.5.2 Specific Growth Rate:

**TABLE 3**

**SPECIFIC GROWTH RATE OF NILE TILAPIA FINGERLINGS FED WITH VARYING LEVELS OF VFWS AFTER 30-DAYS OF FEEDING**

| Treatment | Specific Growth Rate (%) | | | Mean (± SE) |
|---|---|---|---|---|
| | R1 | R2 | R3 | |
| I | 0.1 | 0.8 | 0.9 | 0.60± 0.25$^{ns}$ |
| II | 0.3 | 0.2 | 1.2 | 0.57± 0.32$^{ns}$ |
| III | 0.1 | 0.6 | 0.8 | 0.50± 0.21$^{ns}$ |
| IV | 0.5 | 0.1 | 0.2 | 0.27± 0.12$^{ns}$ |
| *P-value* | | | | 0.7525 |

$^{*}$Significant at P<0.05
$^{ns}$ Not significant

Specific growth rates of Nile tilapia fingerlings given with diets supplemented with varying levels of VFWS are shown in Table 3. The results showed no significant difference among the treatments, respectively. Though statistically not significant, Nile tilapia fed with TI had a numerically higher SGR of 0.6%, indicating that the growth rate of the fingerlings was most optimal under this treatment. Treatment II also showed a relatively high SGR with 0.5667%, closely following Treatment I. Treatment III had a moderate SGR with 0.5%, which was slightly lower than Treatments I and II. Treatment IV had the lowest SGR with 0.2667%, suggesting that the level of silage in this treatment was less effective in promoting growth. Similarly, in the study of Soltan & El-Laithy (2008), found that replacing up to 30% of dietary protein made from fish waste, tomato, and potato by-products (FTPS) as a protein source in Nile tilapia diets had no significant effect on final body weight, body length, weight gain, and specific growth rate of Nile tilapia.

### 3.5.3 Absolute Growth Rate:

**TABLE 4**

**ABSOLUTE GROWTH RATE OF NILE TILAPIA FINGERLINGS FED WITH VARYING LEVELS OF VFWS AFTER 30-DAYS OF FEEDING**

| Treatment | Absolute Growth Rate (g/d) | | | Mean (± SE) |
|---|---|---|---|---|
| | R1 | R2 | R3 | |
| I | 0.01 | 0.07 | 0.08 | 0.05± 0.02$^{ns}$ |
| II | 0.02 | 0.02 | 0.1 | 0.04± 0.03$^{ns}$ |
| III | 0.01 | 0.05 | 0.08 | 0.04± 0.02$^{ns}$ |
| IV | 0.06 | 0.01 | 0.01 | 0.02± 0.0 $^{ns}$ |
| *P-value* | | | | 0.8357 |

$^{*}$Significant at P<0.05
$^{ns}$ Not significant

Data on absolute growth rate (AGR) are shown in Table 4. The fingerlings fed with commercial feeds (TI) showed the highest AGR with 0.0533 g/day, indicating the best growth performance in terms of weight gain per day. Treatments II and III had identical AGR (0.0467 g/day), which were slightly lower than Treatment I. Treatment IV had the lowest AGR (0.0267 g/day), indicating the least favorable weight gain. The *P-value* of 0.8357 suggests that the differences in AGR among the treatments are not statistically significant. This indicates that replacing with VFWS from 10 to 20% level of substitution can still be comparable to the pure commercial diet. Ahmad et al. (2020) found that replacing 50% of soybean meal with tilapia viscera silage did not affect the percent weight gain, average weight gain, specific growth rate, and feed conversion of Nile tilapia. This suggests that tilapia diets containing fermented silage can partially replace FM without adverse effects on tilapia growth performance and feed intake.

### 3.6 Feed Conversion Ratio:

The FCR values of Nile tilapia fingerlings fed with supplemented diets with varying levels of VFWS are presented in Table 5. Treatment II had the best FCR of 2.00, meaning the fish were most efficient in converting feed into body mass under this treatment, followed by treatment I with an FCR of 2.67. Treatment III had a numerically higher value of 3.33, indicating less efficiency compared to Treatment I and II. Treatment IV had the highest FCR of 4.17, suggesting the least efficiency in feed conversion. This is similar to Anizah, Manaf & Halaliyah (2021), the FCR of fermented fish waste with 40% protein level ranging from 1.78 to 2.85 for all dietary treatments. Finally, no significant differences (P>0.05) were observed in the mean feed conversion ratio among all the diets given to Nile tilapia fingerlings indicating a significant feed savings to be achieved by fisherfolks that can be maximized due to a level of up to 20% replacement of the commercial diet. This corresponds to the findings of Srour (2009), who did not find any significant changes (P>0.05) in the feed conversion ratio between the FWSHP and the control group.

**TABLE 5**

**FEED CONVERSION RATIO OF NILE TILAPIA FINGERLINGS FED WITH VARYING LEVELS OF VFWS AFTER 30-DAYS OF FEEDING**

| Treatment | Feed Conversion Ratio | | | Mean (± SE) |
|---|---|---|---|---|
| | R1 | R2 | R3 | |
| I | 6 | 1 | 1 | $2.67 \pm 1.67^{ns}$ |
| II | 3 | 2 | 1 | $2 \pm 0.58^{ns}$ |
| III | 8 | 1 | 1 | $3.33 \pm 2.3^{ns}$ |
| IV | 1.6 | 7 | 3.9 | $4.1 \pm 1.56^{ns}$ |
| *P-value* | | | | $0.8163^{ns}$ |

$^{*}$Significant at P<0.05
$^{ns}$ Not significant

### 3.7 Total Weight Gain of Nile tilapia fingerlings:

**TABLE 6**

**MEAN WEIGHT OF NILE TILAPIA FINGERLINGS BEFORE AND AFTER BEING FED WITH DIETS CONTAINING VARYING LEVELS OF VFWS**

| Treatment | Initial Weight (g) | Final Weight (g) | Weight Gain (g) |
|---|---|---|---|
| I | $8.90^{ns}$ (± 0.59) | $10.59^{ns}$ (± 0.15) | $1.69^{ns}$ (± 0.69) |
| II | $7.30^{*}$ (± 0.51) | $8.62^{*}$ (± 0.24) | $1.31^{ns}$ (± 0.72) |
| III | $9.27^{ns}$ (± 0.82) | $10.67^{*}$ (± 0.53) | $1.39^{ns}$ (± 0.63) |
| IV | $10.07^{*}$ (± 0.29) | $10.87^{*}$ (± 0.64) | $0.80^{ns}$ (± 0.43) |
| *Mean* | 8.89 (± 0.039) | 10.19 (± 0.33) | 1.30 (± 0.06) |
| *P-value* | 0.0544 | 0.0229 | 0.7951 |

***Significant at P<0.05**
***ns Not significant***

The initial and final weight of Nile tilapia fingerlings fed with different inclusion of VFWS in the fish diet for 30 days are presented in Table 6. For the initial weight, a numerically higher value was recorded in Nile tilapia fed with T4 with 10.07g among the treatments. For final weight at 30 days, Nile tilapia fingerlings fed with T4 showed a higher value of 10.87g compared to other treatments. The table compare the initial and final weights of Nile tilapia fingerlings across different treatment. For initial weights, T2 (7.30 ± 0.51) and T4 (10.07 ± 0.29) shows a significant difference (p<0.05). In final weights, significant differences are observed between T2 (8.62 ± 0.24) and both T3 (10.67 ± 0.53), and T4 (10.87 ± 0.64), suggesting that the treatment in T2 significantly affects the growth performance of the fingerlings compared to T3 and T4. However, no significant differences were found between other treatments. For the weight gain, a numerically higher value was recorded in Nile tilapia

fingerlings fed with T2 compared to T4, which had the lowest weight gain. T1 and T3 showed a similar weight gains, with T1 yielding the highest weight gain but statistically insignificant (P>0.05) during all feeding period across different treatments.

**TABLE 7**

**EFFECT OF DIETARY TREATMENTS ON INITIAL AND FINAL WEIGHT OF NILE TILAPIA FINGERLINGS**

| | T-Statistics | *P-Value* |
|---|---|---|
| Initial and Final Weight (g) | -7.02 | 0.0059* |

**Significant at 5% level*

Table 7 shows the results of a paired sample t-test comparing the initial and final weights of the fingerlings. The weight of Nile tilapia increased significantly for each treatment group during the 30-day feeding period. A statistically significant difference (P<0.05) between the initial and final weights is shown by the t-test findings (t (3) = -7.02, p = 0.0059). This implies that the fermented silage diet could be a beneficial feed additive option for Nile tilapia farming, potentially offering a sustainable and cost-effective feeding strategy. This suggests that the diet of fermented vegetable and fish waste silage is effective in promoting weight gain in these fish. These results correspond with Noaman et al. (2015) findings, showing that a 75% inclusion of fermented soybean in Nile tilapia fingerlings' diets led to a significant increase in their final weights.

### 3.8 Economic Analysis of Partial Substitution of Commercial Aquafeed by VFWS:

Table 8 shows the economic benefit of utilizing VFWS at varying replacement levels in the commercial aqua diet. Considering the prohibitive price of the aquafeeds at Php 43.00/kg. Nowadays, maximum inclusion of environment friendly agro by-products particularly undergoing sustainable post-harvest processing such as fermentation of vegetable leftovers and fish viscera is indispensable. The VFWS in the present experiment proved to be acceptable to tilapia in the early growth stage as shown by comparable growth rate and tendency to increase their survival rate. The savings on feed cost generated as replacement levels increased from 10%, 15%, and 20% was Php 310.00, Php 465.00, Php 620.00, respectively. The percentage reduction rates from the commercial diet from 7.21%, 10.81%, and 14.42%, respectively was also documented. At the commercial level for a fisherfolk consuming 10 tons of aquafeed per month equivalent to 11,111 Nile tilapia growers feeding at 14.42% savings for 20% substitution of VFWS to the commercial diet, could result in saving of Php 62,000 per month or Php 744,000 per year. Therefore, the economic benefit of utilizing VFWS is immense and promising. The incorporation of VFWS for Nile tilapia diets results in a significant decrease in feed expenses. This conforms to the results of Soltan & El-Laithy (2008) that up to 22.43% in feed costs per kilogram by including fish silage containing tomato and potato by-products. Similarly with the study of Soltan et al. (2017) achieved a 15.59% reduction in feeding costs by substituting 50% of the Nile tilapia diet with fermented fish by-product silage.

**TABLE 8**

**ECONOMIC BENEFIT OF VFWS AT VARYING REPLACEMENT LEVELS OF CF DIET**

| | Cost/100kg CF (Php) | Cost/kg VFWS (Php) | Total Cost (Php) | Savings (Php) | Percentage Reduction |
|---|---|---|---|---|---|
| T1 (100% CF) | 4,300 | - | 4,300 | - | - |
| T2 (90% CF + 10% VFWS) | 3,870 | 120.00* | 3,990 | 310 | 7.21% |
| T3 (85% CF + 15% VFWS) | 3,655 | 180 | 3,835 | 465 | 10.81% |
| T4 (80% CF + 20% VFWS) | 3,440 | 240 | 3,680 | 620 | 14.42% |

**Transportation cost, labor month/day, equipment*

### 3.9 Comparative Cost of Feeding Commercial Feeds and Vegetable and Fish Waste Silage:

**TABLE 9**
**COMPARATIVE COST AND RETURN ANALYSIS OF 1,000 HEAD TILAPIA GROW-OUT FED WITH PURE COMMERCIAL AQUA DIET AND 85% CF AND 15% VFWS**

| 100% Commercial Feeds | | 85% CF and 15% VFWS |
|---|---|---|
| **Revenue** | | |
| Sales of Tilapia | ₱27,000.00 | ₱27,000.00 |
| **Production Expenses** | | |
| Cost of Fingerlings | ₱1,000.00 | ₱1,000.00 |
| Total Cost of Feeds | ₱8,397.9 | ₱7,138.215 |
| **Total Expenses** | ₱9,397.9 | ₱8,138.215 |
| **Net Income** | ₱17,602.1 | ₱18,861.785 |

**Fingerling cost, cost of CF, feed composition for 85% CF and 15% VFWS, market price of tilapia, feed conversion ratio*

Incorporating 15% VFWS into an 85% CF increases profitability compared to using 100% CF alone as shown in Table 9. Both feeding practices generated the same revenue ₱27,000.00, based on 80% survival rate. However, the production expenses varied due to the feed costs. For 100% CF, the total feed costs were ₱8,397.9, whereas ₱7,138.215 was the total cost for the 85% CF and 15% VFWS. The total expenses were lower, leading to a higher net income of ₱18,861.785 for the 85% CF and 15% VFWS, compared to ₱17,602.1 for 100% CF. After four (4) months of feeding, using 85% CF and 15% VFWS saved ₱1,259.685 compared to using pure CF, while maintaining the same feed conversion ratio (1.085), indicating that the substitution does not compromise feed efficiency. The findings show that substituting a portion of commercial feed with VFWS not only reduces feed costs but also enhances profitability without compromising the growth and market value of the fish. Additionally, the use of VFWS promotes sustainability by utilizing waste products effectively, thus reducing environmental impact. This feeding strategy offers a practical and scalable solution to optimize the feed costs and improve financial income for tilapia farmers while supporting sustainable farming practices.

## IV. SUMMARY

Nile tilapia (*Oreochromis niloticus*) is a valuable freshwater fish species that requires high-quality protein sources in its diet. The need for sustainable protein sources in aquaculture has intensified, driven by the need to reduce reliance on fish meal (FM) as the primary protein component in aquafeeds. Cost constraints further necessitate strategic utilization of alternative protein sources. Therefore, alternative protein sources from vegetable and fish wastes are explored in this study. The study was conducted to determine the effectiveness of incorporating fermented dietary vegetable and fish waste silage into the aquafeeds. The growth performance of the fingerlings was observed over a 30-day feeding trial with varying levels of silage incorporation. Growth parameters measured included survival rate (SR), specific growth rate (SGR), absolute growth rate (AGR), and feed conversion ratio (FCR).

The results showed that there were no significant differences among treatments for all growth parameters. Despite this, T3 with 15% inclusion level of VFWS achieved the highest SR at 80%. T1 which is control, showed the highest SGR and AGR values of 0.6% and 0.0533 g/d respectively. T2 had the most efficient feed utilization, indicated by the lowest FCR. On the other hand, the results of the initial and final weights of the fingerlings indicate a statistically significant difference ($P<0.05$) between initial and final weight over the 30-day feeding period. Therefore, incorporating up 20% of VFWS does not significantly impact the growth parameters of Nile tilapia fingerlings.

## V. CONCLUSION

Growth parameters of Nile tilapia fingerlings were not significantly different between treatments when fermented vegetable and fish waste silage was added to their meals. Still, T1 increased specific growth rates, T2 optimized feed conversion ratio, and T3 with a 15% inclusion level of VFWS in commercial feed increased fingerling survival rates. These findings suggest that silage is a potential feed additive for Nile tilapia. Further research could explore the long-term impacts of utilizing the VFWS to

improve the sustainability and cost-effectiveness of tilapia farming.

## VI. RECOMMENDATIONS

For future experiments, the following recommendations are made:

1) Pelletize the fermented vegetable and fish waste silage to improve feed handling, storage and uniformity in the diets provided to the fish;

2) Conduct feeding trials in fishponds for actual practices to better understand and improve feeding practices;

3) Expand the study to include different fish species to generalize the applicability of VFWS in aquafeeds;

4) Test the Hepatosomatic Index (HSI) and the Stomach Somatic Index (SSI) to assess the health impacts of VFWS on fish growth; and,

5) Perform comprehensive water quality assessments to ensure optimal experimental conditions.

## REFERENCES

[1] Abwao, J., Kyule, D., Junga, J. O., Barasa, J. E., & Sigana, D. A. (2023). On-farm growth performance of different strains of tilapia, *Oreochromis niloticus* reared in earthen ponds. *Aquaculture, Fish and Fisheries, 3*(3), 247–255. https://doi.org/10.1002/aff2.114

[2] Ahmad, N., Siddiqui, P. J. A., Khan, K. M., Ali, A., Tahir, M., Akbar, N. U., & Boneri, I. (2020). Effects of partial substitution of fishmeal by soybean meal in Nile tilapia (*Oreochromis niloticus*) diet. *Journal of Animal and Plant Sciences, 30*(2), 364–370. https://doi.org/10.36899/japs.2020.2.0058

[3] Andriani, Y., Lili, W., Zidni, I., Wiyatna, M. F., & Risdiana, N. (2020). The effect of fermentation process on physical properties of organic material from domestic food waste. *Key Engineering Materials, 860,* 345–350. https://doi.org/10.4028/www.scientific.net/kem.860.345

[4] Andriani, Y., & Pratama, R. I. (2022). Vegetable waste as feed on the growth of tilapia (*Oreochromis niloticus*). *International Journal of Advancements in Research and Technology, 1*(2). https://www.globalscientificjournal.com/researchpaper/vegetable_waste_as_feed_on_the_growth_of_tilapia_oreochromis_niloticus_.pdf

[5] Anizah, M., Manaf, S. R., & Hilaliyah, M. J. N. (2021). Utilization of fish waste as fish meal substitute in formulated fish diet on the growth performance of Nile tilapia fry (*Oreochromis niloticus*). *Food Research, 5*(s4), 21–29. https://doi.org/10.26656/fr.2017.5(s4).001

[6] Asefa, B. G., Melaku, A. Y., & Tsige, F. H. (2021). Growth response of Nile tilapia (*Oreochromis niloticus*) fries fed on silage-based diets. *International Journal of Science and Qualitative Analysis, 7*(1), 30. https://doi.org/10.11648/j.ijsqa.20210701.15

[7] Ayed, L., M'hir, S., & Hamdi, M. (2020). Microbiological, biochemical, and functional aspects of fermented vegetable and fruit beverages. *Journal of Chemistry, 2020,* 1–12. https://doi.org/10.1155/2020/5790432

[8] Bolivar, R., Ferket, P., Stark, C., & Borski, R. (2011). Feeding and feed formulation strategies to reduce production costs of tilapia culture. In *Technical reports: Investigations 2009–2011* (pp. 202–226).

[9] Campang, J. G., & Cruz, E. M. V. (n.d.). Direct-fed microbials as a growth enhancer of genetically male Nile tilapia fry (*Oreochromis niloticus* L.). *Asian Journal of Microbiology, Biotechnology and Environmental Sciences.*

[10] Champneys, T., Genner, M. J., & Ioannou, C. C. (2020). Invasive Nile tilapia dominates a threatened indigenous tilapia in competition over shelter. *Hydrobiologia, 848*(16), 3747–3762. https://doi.org/10.1007/s10750-020-04341-8

[11] Dawood, M. A., Magouz, F. I., Mansour, M., Saleh, A. A., Asely, A. M. E., Fadl, S. E., ... & Al-Misned, F. (2020). Evaluation of yeast fermented poultry by-product meal in Nile tilapia (*Oreochromis niloticus*) feed: Effects on growth performance, digestive enzyme activity, innate immunity, and antioxidant capacity. *Frontiers in Veterinary Science, 6,* 516. https://doi.org/10.3389/fvets.2019.00516

[12] De Arruda, L. F., Borghesi, R., & Oetterer, M. (2007). Use of fish waste as silage: A review. *Brazilian Archives of Biology and Technology, 50*(5), 879–886. https://doi.org/10.1590/S1516-89132007000500016

[13] De Ungria, S. T., Fernandez, L. T. T., Sabado, S. E. F., Santos, J. P. E., Sararaña, A. R. B., & VinceCruz-Abeledo, C. C. (2023). How is fish market waste managed in the Philippines? *Environmental Science and Pollution Research, 30*(17), 49512–49522. https://doi.org/10.1007/s11356-023-25622-4

[14] Fagbenro, O. A., & Jauncey, K. (1994). Chemical and nutritional quality of dried fermented fish silages and their nutritive value for tilapia (*Oreochromis niloticus*). *Animal Feed Science and Technology, 45*(2), 167–176. https://doi.org/10.1016/0377-8401(94)90044-2

[15] Fagbenro, O. A., & Jauncey, K. (1998). Physical and nutritional properties of moist fermented fish silage pellets as a protein supplement for tilapia (*Oreochromis niloticus*). *Animal Feed Science and Technology, 71*(1–2), 11–18. https://doi.org/10.1016/S0377-8401(97)00123-5

[16] Gioacchini, G., Olivotto, I., Ashouri, G., & Carnevali, O. (2023). Effects of feed additives on tilapia reproduction. In *Applied Environmental Science and Engineering for a Sustainable Future* (pp. 61–76). https://doi.org/10.1007/978-3-031-38321-2_3

[17] Gutema, B., Yimer, A., & Hailemichael, F. (2021). Growth response of Nile tilapia (*Oreochromis niloticus*) fries fed on silage-based diets. *HAL (Le Centre Pour La Communication Scientifique Directe).* https://hal.science/hal-03787696

[18] Hisano, H., & De Pietro, P. S. (2013). Growth performance and digestibility of juvenile Nile tilapia fed diets containing acid silage viscera of surubim catfish. *Acta Scientiarum. Animal Sciences, 35*(1). https://doi.org/10.4025/actascianimsci.v35i1.14470

[19] Hossain, U., & Alam, A. K. M. N. (2016). Production of powder fish silage from fish market wastes. *SAARC Journal of Agriculture, 13*(2), 13–25. https://doi.org/10.3329/sja.v13i2.26565

[20] Islam, J., Yap, E. E. S., Krongpong, L., Toppe, J., & Peñarubia, O. R. (2021). Fish waste management – an assessment of the potential production and utilization of fish silage in Bangladesh, Philippines and Thailand. *FAO Fisheries and Aquaculture Circular No. 1216.* https://doi.org/10.4060/cb3694en

[21] Kwikiriza, G., Yegon, M. J., Byamugisha, N., Beingana, A., Atukwatse, F., Barekye, A., Nattabi, J., & Meimberg, H. (2023). Morphometric variations of Nile tilapia (*Oreochromis niloticus* Linnaeus, 1758) local strains collected from different fish farms in south western highland agro-ecological zone, Uganda: Screening strains for aquaculture. *Fishes, 8*(4), 217. https://doi.org/10.3390/fishes8040217

[22] Li, D., Ni, K., Zhang, Y., Lin, Y., & Yang, F. (2019). Fermentation characteristics, chemical composition and microbial community of tropical forage silage under different temperatures. *Asian-Australasian Journal of Animal Sciences, 32*(5), 665–674. https://doi.org/10.5713/ajas.18.0085

[23] Libonatti, C., Agüería, D. A., & Breccia, J. D. (2023). Fish waste silage: A green process for low feedstock availability – A review. *Agronomía Mesoamericana, 34*(2), 51077. https://doi.org/10.15517/am.v34i2.51077

[24] Magbanua, T. O., & Ragaza, J. A. (2024). Selected dietary plant-based proteins for growth and health response of Nile tilapia (*Oreochromis niloticus*). *Aquaculture and Fisheries, 9*(1), 3–19. https://doi.org/10.1016/j.aaf.2022.04.001

[25] Mukta, M. A., Khan, M. M. A., Mian, R. U., & Juice, R. A. (2019). Is tilapia farming financially profitable and efficient? Policy options for sustainable farming. *Journal of the Bangladesh Agricultural University, 17*(1), 92–98. https://doi.org/10.3329/jbau.v17i1.40669

[26] Nath, P. C., Ojha, A., Debnath, S., Sharma, M., Nayak, P. K., Sridhar, K., & Inbaraj, B. S. (2023). Valorization of food waste as animal feed: A step towards sustainable food waste management and circular bioeconomy. *Animals, 13*(8), 1366. https://doi.org/10.3390/ani13081366

[27] Noaman, S., Eid, A., Elsayed, K. M., & Abd-Elfattah, B. (2015). Effect of fermented soybean on growth performance of Nile tilapia (*Oreochromis niloticus*). *Journal of Animal, Poultry and Fish Production, 3*(1), 31–37. https://doi.org/10.21608/japfp.2015.7429

[28] Olagunju, L. K., Dele, P. A., Shaw, Y., Brice, R. M., Orimaye, O. E., Wuaku, M., & Anele, U. Y. (2023). Waste to wealth: Recycling agricultural wastes as feed additives. In *Advances in Biological Sciences Research* (pp. 12–20). https://doi.org/10.2991/978-94-6463-282-8_3

[29] Pandey, S. P., & Upadhyay, R. K. (2022). Dietary and nutritional value of fish and fish origin food products. *Journal of Fisheries Science, 4*(1). https://doi.org/10.30564/jfsr.v4i1.4311

[30] Peñarubia, O. R. (2020). Fish waste management: Turning waste into healthy feed with antimicrobial properties. *Asian Fisheries Science, 33*(s1). https://doi.org/10.33997/j.afs.2020.33.s1.002

[31] Prabu, E., Rajagopalsamy, C. B. T., Ahilan, B., Jeevagan, I. J. M. A., & Renuhadevi, M. (2019). Tilapia – an excellent candidate species for world aquaculture: A review. *Annual Research & Review in Biology, 31*(3), 1–14. https://doi.org/10.9734/arrb/2019/v31i330052

[32] Putra, A. N., Jaenudin, Sofia, F., Mustahal, M., Syamsunarno, M. B., Hermawan, D., & Herjayanto, M. (2019). The utilization of vegetable waste silage as feed ingredient in diets for tilapia (*Oreochromis niloticus*). *IOP Conference Series: Earth and Environmental Science, 383*(1), 012002. https://doi.org/10.1088/1755-1315/383/1/012002

[33] Queiros, Q., Fromentin, J., Gasset, E., Dutto, G., Huiban, C., Métral, L., Leclerc, L., Schull, Q., McKenzie, D. J., & Saraux, C. (2019). Food in the sea: Size also matters for pelagic fish. *Frontiers in Marine Science, 6*, 385. https://doi.org/10.3389/fmars.2019.00385

[34] Raeesi, R., Shabanpour, B., & Pourashouri, P. (2023). Use of fish waste for silage preparation and its application in animal nutrition. *Online Journal of Animal and Feed Research, 13*(2), 79–88. https://doi.org/10.51227/ojafr.2023.13

[35] Romana-Eguia, M. R. R., Eguia, R. V., & Pakingking, R. V. Jr. (2020). Tilapia culture: The basics. *Aquaculture Department, Southeast Asian Fisheries Development Center.* https://repository.seafdec.org.ph/handle/10862/5842

[36] Sanchez, P. A., Cruz, M. L., Manansala, J. V., Espaldon, M. V., Seroje, K. K., Calora, J. F. Jr., & Molintas, E. (2019). Solid waste management and reduction of agricultural post-harvest losses using cold storage: Perceptions of farmers in Benguet, Philippines. *Journal of Environmental Science and Management, 22*(1), 99–108. https://doi.org/10.47125/jesam/2019_1/09

[37] Santana, T. M., De Matos Dantas, F., Santos, D. K. M., Kojima, J. T., Pastrana, Y., De Jesus, R. S., & Gonçalves, L. U. (2023). Fish viscera silage: Production, characterization, and digestibility of nutrients and energy for tambaqui juveniles. *Fishes, 8*(2), 111. https://doi.org/10.3390/fishes8020111

[38] Sheng, L., & Wang, L. (2020). The microbial safety of fish and fish products: Recent advances in understanding its significance, contamination sources, and control strategies. *Comprehensive Reviews in Food Science and Food Safety, 20*(1), 738–786. https://doi.org/10.1111/1541-4337.12671

[39] Siddik, M. A. B., Julien, B., Islam, S. M., & Francis, D. S. (2024). Fermentation in aquafeed processing: Achieving sustainability in feeds for global aquaculture production. *Reviews in Aquaculture.* https://doi.org/10.1111/raq.12894

[40] State of World Fisheries and Aquaculture (SOFIA). (2022). *The State of World Fisheries and Aquaculture 2022: Towards Blue Transformation.* Rome: Food and Agriculture Organization of the United Nations.
https://knowledge4policy.ec.europa.eu/publication/state-world-fisheries-aquaculture-sofia-2022_en

[41] Soltan, M. A., & El-Laithy, S. M. (2008). Evaluation of fermented silage made from fish, tomato, and potato by-products as a feed ingredient for Nile tilapia (*Oreochromis niloticus*). *Egyptian Journal of Aquatic Biology and Fisheries, 12*(1), 25–41.
https://doi.org/10.21608/ejabf.2008.1969

[42] Soltan, M., Im, F., Am, E., & Zead, A. (2017). Possibility of using fermented fish silage as feed ingredient in the diets of Nile tilapia (*Oreochromis niloticus*). *Global Veterinaria, 18*(1), 59–67.

[43] Barroga, A. J. (2000). *Studies on the feeding value of fish silage mixed diets in paddy herded duck and growing lamb* (Unpublished doctoral dissertation). Agriculture Kyushu Tokai University.

[44] Southeast Asian Fisheries Development Center, Aquaculture Department. (1993). Farming tilapia in the Philippines. *Aqua Farm News, 11*(3), 4.

[45] Spring, A., Wetherald, A., Fowler, G., Hunt, G., Russell, H., Udnaes, M., & Shultz, J. (2011). Effect of using cobia waste as silage on the weight and length of Nile tilapia in a recirculating aquaponics system. *The Island School Research Symposium.*
https://www.fishconserve.org/arcel/admin/uploads/FPLP145.pdf

[46] Srour, T. (2009). Fish waste and shrimp head silage as dietary protein sources for Nile tilapia (*Oreochromis niloticus*). *Egyptian Journal of Animal Production, 46*(1), 69–84. https://doi.org/10.21608/ejap.2009.94030

[47] Sugiharto, S., & Ranjitkar, S. (2019). Recent advances in fermented feeds towards improved broiler chicken performance, gastrointestinal tract microecology and immune responses: A review. *Animal Nutrition, 5*(1), 1–10.
https://doi.org/10.1016/j.aninu.2018.11.001

[48] The Fish Site. (2023, March 17). Fish silage: An eco-friendly feed ingredient for aquaculture. https://thefishsite.com/articles/fish-silage-an-eco-friendly-feed-ingredient-for-aquaculture

[49] Valente, L. M. P., Linares, F., Villanueva, J. L. R., Silva, J. M. G., Espe, M., Escórcio, C., ... & Bacelar, M. (2016). Dietary protein source or energy levels have no major impact on growth performance, nutrient utilization or flesh fatty acid composition of market-sized Senegalese sole. *Aquaculture, 453,* 40–48. https://doi.org/10.1016/j.aquaculture.2015.11.028

[50] Valente, L. M. P., Rema, P., Ferraro, V., Pintado, M., Sousa-Pinto, I., Cunha, L. M., & Oliveira, M. B. (2011). Iodine enrichment of rainbow trout flesh by dietary supplementation with the red seaweed *Gracilaria vermiculophylla*. *Aquaculture, 321*(1–2), 189–193. https://doi.org/10.1016/j.aquaculture.2011.09.042.

# Traditional Medicine Practices in Tribal Communities of Wayanad, Kerala: Ethnobotanical Insights and Conservation Challenges for Endangered Species

Mr. Sabu V.U.[1*]; Dr. Jithesh M. P.[2]

[*1]Vayalarikil (H), Kalathuvayal (PO), Ambalavayal. 673593, Wayanad, Kerala,
[2]Assistant Professor & Head, Department of Zoology, St. Mary's College, Sulthan Bathery, Wayanad, Kerala.
*Corresponding Author

Received:- 02 October 2025/ Revised:- 13 October 2025/ Accepted:- 18 October 2025/ Published: 31-10-2025
Copyright @ 2025 International Journal of Environmental and Agriculture Research
This is an Open-Access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (https://creativecommons.org/licenses/by-nc/4.0) which permits unrestricted Non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

***Abstract—*** *Traditional medicine remains a cornerstone of primary healthcare among tribal communities in India, particularly within ecologically sensitive regions such as the Wayanad district of Kerala. The present study documents and analyzes the use of endangered plant species and mud-based remedies in the traditional healthcare practices of Wayanad's indigenous populations. Ethnobotanical surveys, conducted through structured interviews with tribal healers, revealed that multiple threatened species—including medicinal orchids, tree barks, and forest herbs—are integral to treatments for ailments such as respiratory disorders, digestive problems, wounds, and skin infections. Additionally, unique mud-based therapeutic applications were recorded, reflecting deep ecological knowledge and cultural adaptation to the local environment.*

*Findings indicate that over 35% of the documented plant species are currently categorized as vulnerable or endangered under the IUCN Red List, raising concerns over both biodiversity conservation and the continuity of indigenous medical systems. The study highlights that unsustainable harvesting, habitat loss, and limited transmission of traditional knowledge across generations threaten this intricate healthcare tradition. Integrating community-led conservation, sustainable resource management, and policy support is vital to safeguard both the ecological resources and the cultural heritage of these communities.*

*This research underscores the dual urgency of conserving endangered medicinal plants and recognizing traditional healing systems as invaluable reservoirs of knowledge. Protecting these practices not only preserves biodiversity but also contributes to sustainable healthcare solutions in the face of global health and environmental challenges.*

***Keywords— Traditional medicine, Tribal communities, Wayanad, Endangered plants, Medicinal orchids, Ethnobotany, Indigenous knowledge, Biodiversity conservation, Sustainable healthcare, Mud therapy, IUCN Red List.***

## I. INTRODUCTION

Traditional medicine remains one of the most enduring links between biodiversity and cultural heritage in human societies. Globally, the World Health Organization (WHO) estimates that nearly **80% of the world's population relies on traditional medicine** for primary health care. This reliance is particularly strong among indigenous and tribal communities, where ethnomedicinal knowledge forms the foundation of health systems, linking natural resources with well-being and cultural identity.

In India, the role of traditional medicine is profound, with systems such as Ayurveda, Siddha, and Unani coexisting alongside rich tribal ethnomedicinal traditions. Kerala, often known as the "cradle of Ayurveda," also harbors numerous indigenous communities that practice traditional healing using locally available resources. Within Kerala, the **Wayanad district** occupies a unique ecological and cultural niche. Positioned in the Western Ghats, a global biodiversity hotspot, Wayanad is home to diverse tribal groups, including the Paniya, Kurichiya, Kuruma, and Kattunaikka communities. These groups possess deep-rooted knowledge of forest ecosystems, plants, soils, and healing practices that have been passed down through generations.

The ethnomedicinal practices of Wayanad's tribes rely not only on medicinal plants but also on natural resources such as **sacred muds and soils** used in wound healing, detoxification, and ritual purification. Such practices underscore the multidimensional relationship between people and their environment, integrating ecological, spiritual, and therapeutic dimensions. However, the survival of this knowledge is increasingly threatened by habitat degradation, overexploitation, modernization, and declining intergenerational transfer of traditional wisdom.

A pressing concern is the **dependence on endangered plant species**. Several species that form the backbone of tribal medicine are categorized as rare, vulnerable, or endangered under the IUCN Red List and India's Wildlife Protection Act. Examples include *Gloriosa superba* (used for anti-inflammatory and rheumatism treatment), *Rauvolfia serpentina* (for hypertension and snakebites), and *Coscinium fenestratum* (antimicrobial and antidiabetic). Unsustainable harvesting, coupled with deforestation and commercial exploitation, threatens the very resources upon which these medical systems depend.

Documenting and analyzing this knowledge is crucial for three reasons:

1. **Cultural preservation** – safeguarding intangible heritage and tribal identity.
2. **Conservation strategy** – highlighting species at risk and promoting sustainable harvesting.
3. **Scientific validation** – bridging ethnomedicine with pharmacological research for novel drug discovery.

**TABLE 1**
**SELECTED ENDANGERED MEDICINAL PLANT SPECIES USED BY TRIBES IN WAYANAD**

| Botanical Name | Local Name | Traditional Uses | IUCN / National Status |
|---|---|---|---|
| *Gloriosa superba* | Kalihari | Anti-inflammatory, arthritis, snakebite antidote | Vulnerable |
| *Coscinium fenestratum* | Maramanjal | Antimicrobial, antidiabetic, wound healing | Endangered |
| *Rauvolfia serpentina* | Sarpagandha | Hypertension, snakebite, mental disorders | Endangered |
| *Pterocarpus santalinus* | Raktha Chandan | Skin ailments, blood purification | Endangered |
| *Nothapodytes nimmoniana* | Amruta | Cancer therapy (camptothecin alkaloid) | Vulnerable |

These examples illustrate how endangered species form a vital component of traditional medicine while simultaneously being at risk from ecological and anthropogenic pressures.

Another distinctive feature of Wayanad's tribal medicine is the use of **medicinal muds and soils**. Certain clays and soils, often sourced from sacred groves or riverbanks, are applied in treating skin diseases, detoxification therapies, or bone fractures. This aligns with global practices such as geophagy and therapeutic clay use observed in Africa, South America, and Asia, reflecting a shared human heritage of earth-based healing.

The tribal communities of Wayanad embody a living library of ethnomedicinal wisdom, linking endangered plant species and natural resources with holistic healing. Yet, this knowledge is fragile, situated at the intersection of biodiversity conservation, cultural survival, and modern scientific inquiry. A systematic study of these practices not only safeguards indigenous heritage but also contributes to sustainable healthcare and biodiversity management at both local and global scales. This paper seeks to document and analyze the endangered ethnomedicinal resources of Wayanad's tribal communities, with a focus on plant species and mud therapies, while exploring their implications for conservation, healthcare, and global sustainability.

## II. MATERIAL AND METHODS

### 2.1 Study Area:

The study was conducted in **Wayanad district**, located in the northern part of Kerala, India, within the Western Ghats biodiversity hotspot (11°36′–11°58′ N latitude; 75°47′–76°26′ E longitude). Wayanad covers an area of 2,132 km² and is characterized by tropical evergreen and moist deciduous forests, lateritic soils, and elevations ranging from 700–2100 meters above sea level. The district receives an annual rainfall of 2500–3500 mm, supporting a rich diversity of flora. The high forest cover and significant tribal population make it a unique landscape for ethnomedicinal studies.

### 2.2 Target Groups:

The research targeted major indigenous communities of Wayanad, namely the **Kurichiya, Paniya, Kattunaikka, Adiya, and Oorali** tribes. These groups retain rich oral traditions of herbal medicine and mud-based therapies. Traditional healers ("vaidyars"), elderly community members, and women responsible for household healthcare were identified as key informants.

### 2.3 Data Collection:

Data were collected between **2023–2025** using a combination of qualitative and quantitative approaches:

- **Semi-structured interviews** with 40 traditional healers and 80 households across tribal hamlets.
- **Focus group discussions** to cross-validate plant uses and mud therapy practices.
- **Field observations** during guided forest walks with healers, documenting collection, preparation, and administration of remedies.
- **Participatory ranking exercises** to assess perceived efficacy and cultural importance of treatments.

### 2.4 Plant Identification:

Specimens of medicinal plants were collected during field visits. Identification was confirmed by taxonomic experts. Voucher specimens were assigned accession numbers for future reference.

### 2.5 Endangered Status Assessment:

The conservation status of plants was determined using the **IUCN Red List of Threatened Species (2023 update)**. Plants were categorized into Critically Endangered (CR), Endangered (EN), Vulnerable (VU), Near Threatened (NT), and Least Concern (LC).

### 2.6 Data Analysis:

Data were analyzed using ethnobotanical indices:

- **Use-Value (UV):** to assess relative importance of each species.
- **Informant Consensus Factor (ICF):** to evaluate agreement among informants for disease categories.
- **Relative Frequency of Citation (RFC):** to determine commonness of use.
  Plants were further categorized by:

1. Disease treated (respiratory, gastrointestinal, dermatological, musculoskeletal, reproductive).
2. Plant parts used (root, bark, leaf, flower, fruit, seed).
3. Preparation method (decoction, paste, infusion, powder, mud mixture).
4. Conservation status.

**TABLE 2**
**EXAMPLES OF ENDANGERED MEDICINAL PLANTS USED BY TRIBAL COMMUNITIES IN WAYANAD**

| Species | Local Name | Part Used | Ailment Treated | Preparation | Status (IUCN/KSBB) |
|---|---|---|---|---|---|
| *Gloriosa superba* | Kalihari | Tuber | Joint pain, arthritis | Paste with mud | Endangered (EN) |
| *Pterocarpus santalinus* | Rakta Chandan | Bark | Skin infections | Decoction | Endangered (EN) |
| *Rauvolfia serpentina* | Sarpagandha | Root | Hypertension, snakebite | Powder | Vulnerable (VU) |
| *Gymnema sylvestre* | Madhunashini | Leaf | Diabetes | Chewed raw | Near Threatened (NT) |
| *Embelia ribes* | Vidanga | Fruit | Worm infestations | Decoction | Vulnerable (VU) |

## III. RESULTS

### 3.1 Overview of Traditional Knowledge:

The ethnobotanical survey documented **96 medicinal plant species** used by tribal communities of Wayanad, distributed across 48 families. Among these, **21 species (21.8%) were listed as threatened** under IUCN or Kerala State Biodiversity Board categories. Endangered species such as *Gloriosa superba*, *Pterocarpus santalinus*, and *Rauvolfia serpentina* were frequently reported in traditional remedies despite their conservation concern. Mud-based therapies were identified in 12 distinct practices, usually in combination with herbal pastes or decoctions, particularly for musculoskeletal and dermatological disorders.

### 3.2 Disease Categories Treated:

Medicinal applications were grouped into six major categories: respiratory, gastrointestinal, dermatological, musculoskeletal, reproductive, and general systemic ailments (e.g., fever, diabetes, hypertension).

- **Respiratory disorders** (cough, asthma, bronchitis) accounted for **18%** of reported remedies.
- **Gastrointestinal conditions** (diarrhea, indigestion, worm infestations) comprised **23%** of uses.
- **Dermatological conditions** (wounds, infections, skin rashes) represented **19%**.
- **Musculoskeletal ailments** (joint pain, arthritis, sprains) made up **15%**, with many remedies involving mud-based applications.
- **Reproductive health** disorders (menstrual irregularities, infertility, postnatal care) accounted for **10%**.
- **General systemic diseases** (diabetes, fever, hypertension, snakebite) comprised **15%** of treatments.

### 3.3 Plant Parts Used:

Analysis showed that the **leaf** was the most commonly used plant part (34%), followed by **root (21%)**, **bark (15%)**, **fruit/seed (14%)**, **flower (6%)**, and **whole plant (10%)**. Roots and tubers of endangered species (*Rauvolfia serpentina*, *Gloriosa superba*) were particularly significant in traditional medicine but posed greater conservation risks due to destructive harvesting.

### 3.4 Preparation Methods:

Five major preparation techniques were identified:

1. **Decoction (28%)** – common for gastrointestinal and respiratory ailments.
2. **Paste (24%)** – usually applied with mud for skin and musculoskeletal conditions.
3. **Infusion (16%)** – used for fevers and reproductive disorders.
4. **Powder (12%)** – administered for diabetes, hypertension, and snakebite.
5. **Mud-based mixtures (20%)** – combined with plant extracts, applied externally for swelling, fractures, and skin healing.

### 3.5 Quantitative Ethnobotanical Indices:

- **Use-Value (UV):** *Rauvolfia serpentina* (0.62), *Gloriosa superba* (0.57), and *Embelia ribes* (0.52) were the most frequently cited species.
- **Relative Frequency of Citation (RFC):** highest for *Gymnema sylvestre* (0.41), reflecting its wide recognition for diabetes treatment.
- **Informant Consensus Factor (ICF):** values were highest for musculoskeletal disorders (0.82) and dermatological conditions (0.78), indicating strong agreement among informants regarding efficacy.

**TABLE 3**
**DISTRIBUTION OF MEDICINAL PLANT USE BY DISEASE CATEGORY**

| Disease Category | No. of Species Used | % of Total | Common Examples |
|---|---|---|---|
| Respiratory | 17 | 18% | *Adhatoda vasica*, *Ocimum sanctum* |
| Gastrointestinal | 22 | 23% | *Embelia ribes*, *Aegle marmelos* |
| Dermatological | 18 | 19% | *Pterocarpus santalinus*, *Curcuma longa* |
| Musculoskeletal | 14 | 15% | *Gloriosa superba*, *Vitex negundo* |
| Reproductive | 9 | 10% | *Asparagus racemosus*, *Aerva lanata* |
| General systemic | 14 | 15% | *Rauvolfia serpentina*, *Gymnema sylvestre* |

### 3.6 Community Perspectives:

Tribal informants emphasized that traditional medicine is not only therapeutic but also culturally symbolic, strengthening identity and community resilience. Elderly healers reported declining transmission of knowledge to younger generations, raising concerns about cultural erosion. Many participants expressed awareness of plant scarcity, linking overharvesting, deforestation, and reduced availability of key species.

**Key Findings**

1. Endangered species remain central to tribal healing systems despite conservation risks.
2. Mud-based therapies are integrally linked with herbal remedies, especially for musculoskeletal and dermatological ailments.
3. Quantitative indices highlight high consensus on certain species, underscoring their cultural and medicinal value.
4. The erosion of knowledge transmission and ecological degradation threatens both cultural heritage and biodiversity.

**TABLE 4**
**TRADITIONAL USES OF MEDICINAL MUD/CLAY**

| Type of Mud/Clay | Application | Reported Health Benefit | Tribal Group Using |
|---|---|---|---|
| Red lateritic clay | Bone fractures | Bone setting, faster healing | Kurichiya |
| Black alluvial mud | Skin infections | Detoxification, anti-fungal | Paniya |
| White kaolin clay | Stomach ailments | Gastro-protection, antidiarrheal | Kattunaikka |

## IV. DISCUSSION

The results of this study underscore the **critical role of traditional medicine** among tribal communities of Wayanad, where biodiversity, culture, and healthcare are deeply interconnected. The reliance on plants and mud-based therapies reflects both ecological adaptation and cultural resilience. Similar to findings in other parts of the Western Ghats (Ganesan et al., 2019; Nair & Pushpangadan, 2021), the knowledge systems documented here illustrate how indigenous practices provide primary healthcare in remote forested landscapes where modern facilities are often inaccessible.

### 4.1 Endangered Species and Conservation Challenges:

One of the most striking findings is the **continued reliance on endangered and vulnerable species**, such as *Gloriosa superba*, *Pterocarpus santalinus*, and *Rauvolfia serpentina*. These plants remain indispensable in treating musculoskeletal disorders, skin diseases, and systemic ailments like hypertension. However, destructive harvesting of roots and bark raises urgent conservation concerns. Comparable trends are reported globally—such as overharvesting of *Taxus wallichiana* in the Himalayas and *Prunus africana* in Africa—where medicinal demand has contributed to population decline. This highlights the **need for sustainable harvesting protocols**, domestication, and cultivation initiatives that can balance traditional healthcare needs with biodiversity conservation.

### 4.2 Mud Therapy and Cultural Significance:

The integration of **mud-based therapies** into traditional practices distinguishes Wayanad's system from many global counterparts. Mud, often combined with herbal pastes, is applied for joint pain, fractures, and skin infections, reflecting an understanding of soil properties, mineral content, and cooling effects. Similar practices are documented in African and South American indigenous communities, suggesting a broader ethnomedical recognition of earth materials as therapeutic. Yet, systematic scientific validation of mud therapy remains limited, calling for interdisciplinary research to bridge **ethnomedicine and biomedicine**.

### 4.3 Knowledge Transmission and Cultural Erosion:

The study also reveals a decline in intergenerational transmission of ethnomedicinal knowledge, echoing patterns across indigenous societies worldwide (Albuquerque et al., 2022). Younger generations are increasingly oriented toward formal healthcare and wage labor, leading to the erosion of orally transmitted traditions. Without urgent documentation and community-led education, this intangible heritage faces irreversible loss. Integrating traditional healers into **community health programs** and promoting school-based ethnobotany curricula could provide pathways to sustain this knowledge while respecting intellectual property rights.

### 4.4 Quantitative Insights and Global Relevance:

The high Informant Consensus Factor (ICF) values for musculoskeletal and dermatological disorders demonstrate **strong cultural agreement** on the efficacy of certain species. This consensus not only validates the perceived effectiveness of remedies but also provides a scientific basis for prioritizing species in **pharmacological screening**. Similar methodological approaches in Latin America and Southeast Asia have successfully identified bioactive compounds later developed into pharmaceuticals. Thus, Wayanad's ethnomedicine holds potential contributions to **global drug discovery** if explored ethically and sustainably.

### 4.5 Policy and Sustainability Dimensions:

At the policy level, the findings align with **global conventions** such as the Convention on Biological Diversity (CBD) and the Nagoya Protocol, which emphasize fair benefit-sharing, conservation of genetic resources, and respect for indigenous knowledge. In India, frameworks under the National Biodiversity Act (2002) and Kerala State Biodiversity Board provide opportunities to integrate tribal healers into conservation and healthcare strategies. Establishing **community-managed medicinal plant reserves**, promoting cultivation of endangered species in home gardens, and linking with herbal cooperatives could reduce harvesting pressure on wild populations while ensuring livelihood support.

### 4.6 Integrating Traditional and Modern Systems:

Finally, the study highlights the importance of moving beyond a dichotomy between "traditional" and "modern" medicine. In resource-limited settings, both systems can be complementary. For example, integrating tribal healers into **primary healthcare networks** could enhance outreach, especially for preventive care and chronic conditions. At the same time, scientific validation of mud and plant-based remedies can increase their acceptance in broader healthcare contexts. Such integrative approaches are increasingly advocated in global health discussions, particularly under the **WHO Traditional Medicine Strategy (2014–2023)**.

### 4.7 Conclusion of Discussion:

Overall, the findings from Wayanad illustrate how **traditional medicine serves as both a healthcare system and a cultural identity marker** for tribal groups. Yet, the dual pressures of ecological degradation and cultural erosion pose significant threats. By situating this study within a global framework, it becomes clear that safeguarding tribal ethnomedicine is not merely a local issue but part of a **larger movement to protect biocultural diversity.** Collaborative conservation, community empowerment, and respectful integration of traditional practices into modern health systems offer a sustainable pathway forward.

## V. CONCLUSION

This study highlights the enduring significance of **traditional medicine** in the tribal communities of Wayanad, Kerala, where biodiversity, culture, and healthcare intersect. The findings demonstrate that indigenous groups such as the Kurichiya, Paniya, and Kattunaikka continue to rely on plant-based and mud therapies to meet primary healthcare needs, particularly for musculoskeletal, dermatological, and systemic disorders. However, the documentation also reveals that several of the species

most valued for their medicinal properties, including *Gloriosa superba*, *Pterocarpus santalinus*, and *Rauvolfia serpentina*, fall within endangered or vulnerable categories. This dual reality underscores both the resilience of indigenous healthcare systems and the fragility of their ecological foundations.

The integration of **mud-based therapies**, a relatively underexplored dimension of ethnomedicine, reflects the innovative ways in which local communities engage with their environment. Such practices not only hold cultural significance but also present opportunities for interdisciplinary scientific exploration, bridging ethnobotany, soil science, and pharmacology.

Yet, the sustainability of this knowledge system is at risk. Intergenerational transmission is declining, driven by cultural change, modernization, and limited recognition of indigenous healers. Without active documentation, conservation, and integration into healthcare and policy frameworks, both biological resources and intangible cultural heritage may be lost.

Importantly, our rich legacy of traditional knowledge on medicinal plants, bio-resources, and their applications deserves **protection and recognition through patent filings.** Such measures safeguard indigenous intellectual property while promoting cultural heritage on a global platform. Equally vital is ensuring that **tribal communities with expertise in traditional healing** are eligible for **government incentives and support**, comparable to those offered for commercial crops and products. These initiatives would encourage preservation, innovation, and sustainable promotion of traditional knowledge systems.

Globally, these findings resonate with broader concerns in ethnomedicine and biodiversity conservation, aligning with international conventions such as the CBD and the Nagoya Protocol, which advocate protection of indigenous knowledge and equitable benefit-sharing.

Ultimately, the preservation of traditional medicine in Wayanad is vital not only for **tribal health security** but also for safeguarding **biocultural diversity**. Protecting these practices contributes to ecological balance, supports local livelihoods, and enriches global scientific understanding—ensuring that indigenous wisdom continues to inspire sustainable healthcare solutions for generations to come.

## ACKNOWLEDGMENT

I sincerely express my gratitude to **Eunoia Orchid Garden** for providing invaluable support and inspiration throughout this research. The garden's dedication to conservation and biodiversity offered critical insights into plant management and sustainable practices. I also extend my heartfelt thanks to the tribal communities of Wayanad for sharing their traditional knowledge with openness and trust. Their cooperation made this study possible and enriched it with cultural and ecological depth.

## REFERENCES

[1] Anuradha, R., & Sivakumar, G. (2020). Traditional medicinal practices and biodiversity conservation: A study on indigenous knowledge systems in South India. *Journal of Ethnobiology and Ethnomedicine, 16*(1), 45. https://doi.org/10.1186/s13002-020-00394-8

[2] Balick, M. J., & Cox, P. A. (2021). *Plants, people, and culture: The science of ethnobotany* (2nd ed.). CRC Press.

[3] Bhagwat, S. A., & Rutte, C. (2006). Sacred groves: Potential for biodiversity management. *Frontiers in Ecology and the Environment, 4*(10), 519–524. https://doi.org/10.1890/1540-9295

[4] Chandrasekharan, C., & Sankar, S. (1998). *Medicinal plants of India: Guidelines for conservation and sustainable utilization*. Ministry of Environment and Forests, Government of India.

[5] Ganesan, S., Venkateshan, G., & Babu, D. K. (2017). Traditional medicine and its role in primary healthcare among tribal communities of Tamil Nadu. *Indian Journal of Traditional Knowledge, 16*(4), 609–615.

[6] Heinrich, M., Barnes, J., Gibbons, S., & Williamson, E. (2018). *Fundamentals of pharmacognosy and phytotherapy* (3rd ed.). Elsevier.

[7] Kala, C. P. (2015). Indigenous uses, population density, and conservation of threatened medicinal plants in the Indian Himalayan Region. *Conservation Biology, 29*(2), 429–438. https://doi.org/10.1111/cobi.12404

[8] Kunhikannan, C., & Nagarajan, M. (2016). Ethnomedicinal knowledge of tribal communities in the Western Ghats: Relevance for sustainable forest management. *Journal of Forestry Research, 27*(3), 641–651. https://doi.org/10.1007/s11676-016-0180-5

[9] Myers, N., Mittermeier, R. A., Mittermeier, C. G., Da Fonseca, G. A., & Kent, J. (2000). Biodiversity hotspots for conservation priorities. *Nature, 403*(6772), 853–858. https://doi.org/10.1038/35002501

[10] Nair, K. N., & Jayakumar, K. (2022). Traditional ecological knowledge and medicinal plant use among tribal communities of Kerala, India. *Journal of Ethnopharmacology, 283,* 114713. https://doi.org/10.1016/j.jep.2021.114713

[11] World Health Organization. (2013). *WHO traditional medicine strategy: 2014–2023*. World Health Organization.

# Status of Zinc Content in Soils and Rice Genotypes and its Relationship with Soil Chemical Properties across different Agro-Climatic Zones of Karnataka, South India

Chakpram Birendrajit[1*]; Prakash Nagabovanalli[2]

[*1]Assistant Professor (Soil Science), Department of Basic Engineering and Applied Science, College of Agricultural Engineering and Post Harvest Technology, Central Agricultural University, Ranipool-737135, Gangtok, Sikkim, India; [2]Professor, Department of Soil Science & Agricultural Chemistry, College of Agriculture, University of Agricultural Sciences, Bengaluru-560065, Karnataka, India
*Corresponding Author

Received:- 03 October 2025/ Revised:- 09 October 2025/ Accepted:- 15 October 2025/ Published: 31-10-2025
Copyright @ 2025 International Journal of Environmental and Agriculture Research
This is an Open-Access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (https://creativecommons.org/licenses/by-nc/4.0) which permits unrestricted Non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

***Abstract—***

***Background and Aims:*** *Billions of people suffer from Zn deficiency globally. Rice, being an important source of Zn in the diet, a study was carried out to access the status of Zn in soils and rice genotypes and also study the relationship of soil pH, OC and DTPA-Zn with Zn content in grain and straw of rice.*

***Methods:*** *A total of 244 rice and soil samples comprising 64 different rice genotypes were collected from eight agro-climatic zones of Karnataka. The status of Zn in rice and soils were analyzed.*

***Results:*** *The results revealed that DTPA-Zn content in soil ranged from 0.2 to 4.5 mg $kg^{-1}$ across eight ACZ. The grain and straw Zn content of 244 rice samples comprising of 64 rice genotypes ranged from 7.8 to 51.3 mg $kg^{-1}$ and 16.6 to 284.0 mg $kg^{-1}$, respectively. The Zn content of grain and straw was positive significantly correlated with OC and DTPA-Zn whereas negative significantly correlated with soil pH.*

***Conclusion:*** *The problem of low Zn content in rice may be overcome through proper understanding of the relationship between the rice plant and soil chemical properties such as soil pH, DTPA-Zn and OC and adoption of proper management practices accordingly.*

***Keywords— Rice genotypes, grain and straw Zn content, soil pH, organic carbon, DTPA-Zn.***

***Abbreviation***

*ACZ – Agro-climatic zone; AAS – Atomic Absorption Spectrophotometer; DTPA-Zn – Diethylene Triamine Penta Acetic Acid Extractable Zn.*

## I. INTRODUCTION

Micronutrient malnutrition has affected lives of billions as evident by 2.7 billion suffering from Zn deficiency all over the world (Anon 2004). In India, 27 per cent of total population is affected by Zn deficiency related disorders such as poor immune system, diarrhoea, poor physical and mental health (WHO 2007). Zn deficiency claims about 4.4 per cent of the total child deaths in the world (Black 2003).

Rice is the important staple food for more than half of the world population and provides 60 to 70 per cent body calorie intake to the consumers and is consumed in large amounts. Rice is the staple food of nearly 65 per cent of the total population in India (Barah 2005). Because of the high consumption of rice in developing countries and its inherent low Zn content, the extra Zn would have meaningful impact on human nutrition and health. A little increase in grain nutritive value of rice will produce a cumulative effect on total nutrient intake (Chandel et al. 2010).

Nutritional requirement of micronutrient should be met from micronutrient output of modern agricultural systems. Accordingly, knowledge on micronutrient status in soil and crop edible tissues is necessary. Katyal and Sharma (1991) indicated the variation in Zn content of different major soils forming rocks of India. Available Zn content in surface soils of India ranged from 0.08 to 20.5 ppm. There is a wide variation in agricultural soils across the globe in Zn content and their capacity to supply Zn for optimal crop growth (White and Zasoki 1999). Alloway (2008) reported worldwide deficiency of Zn in soils. Zinc deficiency was reported in the soils of Turkey (Cakmak 2002), China (Liu 1991), Java (Soepardi 1982), Australia (Sillanpaa 1990) and in India (Takkar 1996; Singh 2001; Behera et al. 2009). About 48 per cent of Indian soils are deficient in Zn (Sakal 2001). Zn deficiency in soils of Karnataka is up to the extent of 78 per cent (Singh and Saha 1995). It is generally prevalent in high pH calcareous soils (Liu et al. 1983; Katyal and Vlek 1985). But it has also been reported in acid soils which are leached and heavily weathered (Alloway 2008 and Behera 2011).

Plant availability of Zn in soils is influenced by many factors (Shuman 1986). Besides soil organic carbon (OC) content, one of the most important soil properties influencing Zn availability in soil is soil pH (Anderson and Christensen 1988). Usually extractable Zn decreases with an increase in soil pH due to increased absorptive capacity, the formation of hydrolyzed forms of Zn, possible chemisorptions on calcium carbonate and co-precipitation as iron oxides (Cox and Kamprath 1972; Alloway 2008).

The incidence of Zn deficiencies in crops has increased markedly in recent years due to intensive cropping, loss of top soils by erosion, losses of micronutrients through leaching, liming of acid soils, decreased proportions of farmyard manure compared to chemical fertilizers, increased use of high analysis NPK fertilizers coupled with use of Zn free fertilizers and use of marginal lands for crop production. Micronutrient deficiency problems are also aggravated by the high demand of modern crop cultivars (Fageria et al. 2002). As a result, Zn content in plant dry matter is low particularly in grain. Since all of the micronutrients that human consume are derived from the soil-plant system. Therefore, identification of high grain Zn containing rice genotypes is needed to ensure adequate attainment of mineral element in daily diet.

In the context of the above facts, the present study was carried out to (i) access the status of Zn in soils and rice genotypes (ii) study the relationship of selected soil chemical properties such as soil pH, OC and DTPA-Zn with Zn content in grain and straw of rice.

## II. MATERIALS AND METHODS

### 2.1 Sampling location:

A survey work was conducted to determine the status of Zn content in different rice genotypes and rice growing soils under various rice growing agro-climatic zones (ACZ) of Karnataka. The state of Karnataka has been classified into ten ACZ (Zone 1 to 10) which was categorized based on soil type, cropping pattern, rainfall and soil parent material.

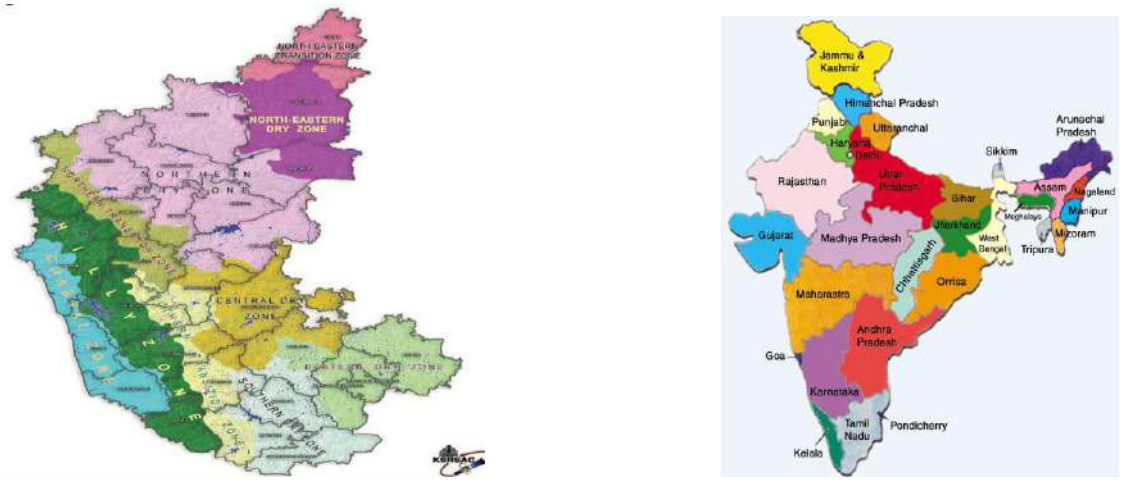



**FIGURE 1: Soil and plant sampling sites representing different ACZ of Karnataka, India**

Out of ten zones, samples were collected from eight ACZ viz. North Eastern Dry Zone (Zone 2) denoted by NEDZ, Northern Dry Zone (Zone 3) denoted by NDZ, Central Dry Zone (Zone 4) denoted by CDZ, Southern Dry Zone (Zone 6) denoted by SDZ, Southern Transition Zone (Zone 7) denoted by STZ, Northern Transition Zone (Zone 8) denoted by NTZ, Hilly Zone

(Zone 9) denoted by HZ and Coastal Zone (Zone 10) denoted by CZ as shown in Fig.1. The rice plant (grain and straw) and soil samples were collected from farmers' field. Effort was made to collect as many rice genotypes as possible from each zone to know the variations in Zn content in plant and soil samples. This study was conducted in the following steps:

1) Representative soil, rice grain and straw samples were collected at the time of harvest from different farmers' fields representing eight ACZ of Karnataka. The soil samples were collected from the same field where the plant samples had been collected.
2) From each zone, more than two prominent genotypes were collected depending on the availability. For each genotype, a minimum of two different farmers' field was selected for sampling from each zone. In some of the ACZ, single rice genotype was also collected to make representation of the zone.
3) Plant and soil sampling, and analytical methods for soil pH, Electrical Conductivity (EC), OC, Zn content in soil (DTPA extractable) and plant (grain and straw) are given below

### 2.2 Soil sampling and processing:

The soil samples were collected from rice fields of eight ACZ of Karnataka. The composite soil samples were prepared for all the soil samples collected and allowed to air dry in shade. The air dried soil samples were pounded with wooden plank and sieved in 2 mm and 0.2 mm (for OC estimation) mesh sieve. The soil samples were stored in plastic container with proper labeling for further use.

### 2.3 Plant sampling and its preparation:

The collected rice samples from different ACZ of Karnataka were separated into grain and straw. Rice straw was first washed in tap water followed by 0.1 *N* HCl to remove any surface contaminants. It was again washed twice in glass double distilled water (DDW) immediately to remove any acid residues. The rice straw and grain was dried in the hot-air oven at 65° C for 48 and 72 hours respectively. The dried straw samples were cut into smaller pieces and powdered in stainless steel grinder. The stainless-steel jar was cleaned thoroughly and wiped with distilled alcohol after each and every sample to avoid any contamination.

The dried rice grain was de-husked manually by hand to avoid any kind of contamination. Washing of hand was followed for each and every sample with distilled alcohol to prevent sample to sample contamination. The de-husked grains were washed first in DDW and followed by 0.1 *N* HCl. It was washed thrice in DDW immediately to remove the acid residues from the surface of grain and dried in the hot-air oven at 65° C for 24 hours.

### 2.4 Routine soil analysis:

Determination of soil chemical properties like soil pH and EC was conducted on 1:2.5 soil water ratio (w/v) suspension using pH meter and EC meter following half an hour equilibration (Jakson 1973). Soil organic carbon content was estimated by the Walkley and Black (1934) method.

The extracting solution used for extracting Zn from soil consisted of 0.005 *M* Diethylene triamine penta acetic acid (DTPA) + 0.001 *M* $CaCl_2.2H_2O$ + 0.1 *N* Triethanolamine buffered at pH 7.3 (Lindsay and Norwell 1978). Ten grams of soil was shaken with 20 ml of extracting solution for 2 hours and the soil solution was further filtered. Zn content was determined from the extract using AAS (Perkin Elmer, Analyst 400)

### 2.5 Zinc content in soil:

A known quantity of sample (grain and straw) was treated with 3 ml of $H_2O_2$ and later with 7 ml of $HNO_3$ and digested using microwave digestion system (Milestone - Start D) programmed with following steps: 1000 watts for 20 minutes at 150ºC (Ramping) and 1000 watts for 10 minutes at 150ºC (Holding) followed by 10 minutes of venting. The digested sample was made up to 50 ml volume and analyzed for Zn content in grain and straw samples with the help of AAS.

### 2.6 Zinc content in plant:

A correlation coefficient matrix was established by using SPSS software version 20.0 taking all samples together to study the effect of selected soil chemical properties such as soil pH, EC, OC and DTPA-Zn on the occurrence of Zn content in grain and straw.

## III. RESULTS

### 3.1 Status of Zn in soils and rice genotypes:

The details of the genotypes and the GPS coordinates of the sampling sites are given in Table 1. Table 2 shows the analytical results of chemical properties of soil (soil pH, EC and OC), Zn content in rice (grain and straw) and soil samples (DTPA extractable) collected from eight ACZ of Karnataka.

The soil pH ranged from 5.9 to 8.8 (mean of 7.9), 5.0 to 7.5 (mean of 6.3), 4.9 to 8.5 (mean of 6.4), 5.1 to 8.8 (mean of 6.9), 4.7 to 7.5 (mean of 5.5), 4.8 to 6.9 (mean of 5.8), 4.7 to 7.6 (mean of 5.4) and 4.5 to 6.4 (mean of 5.7) in the soils of NEDZ, NDZ, CDZ, SDZ, STZ, NTZ, HZ and CZ, respectively (Table 2). Similarly, EC ranged from 0.08 to 1.71 $dSm^{-1}$ (mean of 0.64 $dSm^{-1}$), 0.07 to 0.57 $dSm^{-1}$ (mean of 0.19 $dSm^{-1}$), 0.06 to 0.84 $dSm^{-1}$ (mean of 0.24 $dSm^{-1}$), 0.07 to 1.48 $dSm^{-1}$ (mean of 0.39 $dSm^{-1}$), 0.06 to 0.59 $dSm^{-1}$ (mean of 0.21 $dSm^{-1}$), 0.04 to 0.63 $dSm^{-1}$ (mean of 0.26 $dSm^{-1}$), 0.02 to 0.4 $dSm^{-1}$ (mean of 0.1 $dSm^{-1}$), 0.04 to 0.73 $dSm^{-1}$ (mean of 0.21 $dSm^{-1}$) in the soils of NEDZ, NDZ, CDZ, SDZ, STZ, NTZ, HZ and CZ, respectively (Table 2).

The OC content ranged from 0.11 to 0.35 per cent (mean of 0.19 per cent), 0.17 to 0.39 per cent (mean of 0.30 per cent), 0.19 to 0.55 per cent (mean of 0.33 per cent), 0.21 to 0.55 per cent (mean of 0.36 per cent), 0.25 to 0.62 per cent (mean of 0.39 per cent), 0.24 to 0.64 per cent (mean of 0.41per cent), 0.28 to 0.74 per cent (mean of 0.49 per cent) and 0.17 to 0.54 per cent (mean of 0.35 per cent) in the soils of NEDZ, NDZ, CDZ, SDZ, STZ, NTZ, HZ and CZ, respectively (Table 2).

The DTPA-Zn content ranged from 0.3 to 1.0 mg $kg^{-1}$ (mean of 0.6 mg $kg^{-1}$), 0.3 to 1.0 mg $kg^{-1}$ (mean of 0.7mg $kg^{-1}$), 0.3 to 3.2 mg $kg^{-1}$ (mean of 0.9 mg $kg^{-1}$), 0.3 to 2.4 mg $kg^{-1}$ (mean of 0.9 mg $kg^{-1}$), 0.3 to 3.5 mg $kg^{-1}$ (mean of 1.0 mg $kg^{-1}$), 0.2 to 1.2 mg $kg^{-1}$ (mean of 0.7 mg $kg^{-1}$), 0.3 to 4.5 mg $kg^{-1}$ (mean of 1.4 mg $kg^{-1}$) and 0.4 to 1.2 mg $kg^{-1}$ (mean of 0.7 mg $kg^{-1}$) in the soils of NEDZ, NDZ, CDZ, SDZ, STZ, NTZ, HZ and CZ, respectively (Table 2).

The Zn content of grain ranged from 12.5 to 24.5 mg $kg^{-1}$ (mean of 16.0 mg $kg^{-1}$), 11.4 to 26.9 mg $kg^{-1}$ (mean of 16.8 mg $kg^{-1}$), 12.3 to 25.8 mg $kg^{-1}$ (mean of 18.1 mg $kg^{-1}$), 7.8 to 21.2 mg $kg^{-1}$ (mean of 14.2 mg $kg^{-1}$), 10.1 to 39.6 mg $kg^{-1}$ (mean of 22.4 mg $kg^{-1}$), 18.1 to 28.8 mg $kg^{-1}$ (mean of 23.8 mg $kg^{-1}$), 12.7 to 45.4 mg $kg^{-1}$ (mean of 24.0 mg $kg^{-1}$) and 16.5 to 51.3 mg $kg^{-1}$ (mean of 27.9 mg $kg^{-1}$) in the grain samples collected from NEDZ, NDZ, CDZ, SDZ, STZ, NTZ, HZ and CZ, respectively (Table 2). Whereas, the Zn content of straw ranged from 22.3 to 46.5 mg $kg^{-1}$ (mean of 34.4 mg $kg^{-1}$), and 24.3 to 64.8 mg $kg^{-1}$ (mean of 45.9 mg $kg^{-1}$), and 30.5 to 58.0 mg $kg^{-1}$ (mean of 42.9 mg $kg^{-1}$), and 16.6 to 102.3 mg $kg^{-1}$ (mean of 43.6 mg $kg^{-1}$), and 20.8 to 284.0 mg $kg^{-1}$ (mean of 58.6 mg $kg^{-1}$), and 33.3 to 72.3 mg $kg^{-1}$ (mean of 53.3 mg $kg^{-1}$), and 36.3 to 94.5 mg $kg^{-1}$ (mean of 62.1 mg $kg^{-1}$) and 40.5 to 90.3 mg $kg^{-1}$ (mean of 60.6 mg $kg^{-1}$) in the straw samples collected from NEDZ, NDZ, CDZ, SDZ, STZ, NTZ, HZ and CZ, respectively (Table 2).

It was observed that Zn was applied in 67, 21, 57, 28, 14, 36 and 38 per cent of the soil samples collected from farmers' field representing NEDZ, NDZ, CDZ, SDZ, STZ, HZ and CZ, respectively (Table 2). In overall, 34 per cent of the collected soil samples were below the critical limit of Zn in soil.

In general, soil pH, EC, OC, DTPA-Zn, grain Zn and straw Zn ranged from 4.5 to 8.8 (mean of 6.3), 0.02 to 1.71 $dSm^{-1}$ (mean of 0.29 $dSm^{-1}$), 0.11 to 0.74 per cent (mean of 0.36 per cent), 0.2 to 4.5 mg $kg^{-1}$ (mean of 0.9 mg $kg^{-1}$), 7.8 to 51.3 mg $kg^{-1}$ (mean of 19.8 mg $kg^{-1}$) and 16.6 to 284.0 mg $kg^{-1}$ (mean of 50.8 mg $kg^{-1}$), respectively in all the collected soil and plant samples.

### 3.2 Variation among the rice genotypes in Zn content of grain and straw:

A total of 244 rice samples (grain and straw) were collected comprising of 64 rice genotypes from eight ACZ of Karnataka, India. Among the different rice genotypes, five commonly grown genotypes were selected for studying the variation in Zn content of rice grain and straw. The Sona was collected as the largest number of samples (n=50) among the different rice genotypes followed by JGL (n=17), MTU-1001 (n=15), Jyothi (n=15) and MTU-1010 (n=11) as presented in Table 3.

The grain and straw Zn content of Sona genotype was ranged from 12.5 to 36.1 mg $kg^{-1}$ and 22.3 to 90.3 mg $kg^{-1}$ with a mean of 18.1 mg $kg^{-1}$ and 40.2 mg $kg^{-1}$, respectively (Table 3). For JGL genotype, Zn content for grain and straw was ranged from 7.9 to 33.3 mg $kg^{-1}$ and 25.2 to 75.7 mg $kg^{-1}$ with a mean of 19.1 mg $kg^{-1}$ and 44.5 mg $kg^{-1}$, respectively. The grain and straw Zn content of MTU-1001 genotype was ranged from 8.9 to 27.9 mg $kg^{-1}$ and 24.3 to 75.3 mg $kg^{-1}$ with a mean of 17.3 mg $kg^{-1}$ and 45.1 mg $kg^{-1}$, respectively. In case of Jyothi genotype, the Zn content of grain and straw was ranged from 10.5 to 51.3 mg $kg^{-1}$ and 17.5 to 90.7 mg $kg^{-1}$ with a mean of 22.4 mg $kg^{-1}$ and 52.6 mg $kg^{-1}$, respectively. For MTU-1010 genotype, the Zn content of grain and straw was ranged from 11.4 to 26.0 mg $kg^{-1}$ and 33.8 to 79.8 mg $kg^{-1}$ with a mean of 20.4 mg $kg^{-1}$ and 57.5

mg $kg^{-1}$, respectively. In general, the grain and straw Zn content across 64 rice genotypes ranged from 7.9 to 51.3 mg $kg^{-1}$ and 16.6 to 284.0 mg $kg^{-1}$ with a mean of 19.8 mg $kg^{-1}$ and 50.8 mg $kg^{-1}$, respectively (Table 3).

### 3.3 Categorization of rice growing soils and rice genotypes based on their Zn content:

An attempt has been made to categorize the collected 244 soil and plant samples comprising of 64 rice genotypes from eight ACZ of Karnataka based on the Zn content in soils, grain and straw as shown in Table 2 and 4.

**TABLE 1**
**DETAILS OF THE GENOTYPES COLLECTED FROM DIFFERENT ACZ OF KARNATAKA, INDIA AND GPS COORDINATES OF THE SAMPLING SITES**

| Sl. no. | Agro-climatic zones | *n | Latitude | Longitude | No. of genotypes | Genotypes collected |
|---|---|---|---|---|---|---|
| 1 | North Eastern Dry Zone (NEDZ) | 30 | N 15°32'10.9" – N 16°35'11.5" | E 75°46'27.8" – E 76°47'08.9" | 1 | Sona |
| 2 | Northern Dry Zone (NDZ) | 14 | N 14°36'10.0" – N 14°39'23.8" | E 75°11'54.8" – E 75°15'49.1" | 5 | MTU-1001, MTU-1010, JGL, Sona and Jyothi |
| 3 | Central Dry Zone (CDZ) | 14 | N 14°16'37.2" – N 14°28'5.6" | E 75°44'47.3" – E 75°57'53.5" | 2 | JGL and Sona |
| 4 | Southern Dry Zone (SDZ) | 48 | N 12°03'27.4" – N 12°52'28.8" | E 75°54'45.0" – E 77°05'12.9" | 22 | Rajamudi, Aryza-6444, KRH-2, MTU-1001, BR-2655, Jaya, Rasi, Thanu, Prakash, Nagamani, GK-5003, Sona, Ankush, Gagana, KMP-149, KMP-150, KCP-1, Jyothi, IR-64, NLR, Raksha and JGL |
| 5 | Southern Transition Zone (STZ) | 50 | N 13°43'39.8" – N 14°36'39.0" | E74°50'43.5" – E 075°44'27.8" | 21 | MTU-1001, Sanabatta, Jaya, Sona, Jyothi, JGL, MO-4, MTU-1010, Sonalam, Abhilashu, Lokanatha, Thunga, Jeerge Sanna, Siri-1253, Basmati, Intaan, Hemavati, Siddhagiri-2, IET-9926 and Warangal Batta |
| 6 | Northern Transition Zone (NTZ) | 17 | N 14°59'1.9" – N 15°02'8.7" | E 75°03'33.8" – E 75°09'33.3" | 5 | Jaya, Sona, MTU-1010, Intaan, and Doddige |
| 7 | Hilly Zone (HZ) | 45 | N 12°08'41.6" – N 13°21'53.8" | E 75°38'29.8" – E 75°56'29.8" | 32 | IR-20, Intaan, Annekal Batta, Holesalu, IR-64, Uddara Mallige, Kesari Batta, Kirwana, Billi Batta, PUBM-8, Sharavati, KHP-9, BKBM-23, Hemavati, KHP-2, Thunga, KHP-5, IET-7191, Abhilasu, Putta Batta, AVT-2, KHRS-28, Thirthalli, CTH-1, CTH-3, BR-2655, Jyothi, JGL, KHP-10, KMP-148, Doddi and BKV |
| 8 | Coastal Zone (CZ) | 16 | N 13°25'53.3" – N 13°49'09.1" | E 74°38'53.0" – E 74°46'10.3" | 6 | MO-4, KCP-1, Phalguna, Champaka, Thunga and Jyothi |
| | Total | 244 | | | 64 | |

***n= number of plant sample***

#### 3.3.1 Rice growing soils:

The results of the present investigation revealed that 26.7 (NEDZ), 35.7 (NDZ), 35.7 (CDZ), 13.8 (SDZ), 26.0 (STZ), 35.3 (NTZ), 20.0 (HZ) and 50 (CZ) per cent of the collected soil samples were found to be deficient in available Zn which is below the general soil critical limit of 0.6 mg $kg^{-1}$ Zn in soil as given by Katyal and Rattan (2003). In general, 34 per cent out of 244 soil samples collected from eight ACZ of Karnataka were found below the critical limit of Zn in soil (Table 2).

**TABLE 2**

**SOIL pH, EC, Zn CONTENT OF SOILS, GRAIN AND STRAW OF RICE ACROSS DIFFERENT ACZ OF KARNATAKA, INDIA**

| ACZ | *n | | pH | EC ($dSm^{-1}$) | OC (%) | DTPA-Zn (mg $kg^{-1}$) | Grain (mg $kg^{-1}$) Zn | Straw (mg $kg^{-1}$) Zn | Zn deficiency (%) | Zn application (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| NEDZ | 30 | Mean | 7.9 | 0.64 | 0.19 | 0.6 | 16 | 34.4 | 26.7 | 67 |
| | | Range | 5.9-8.8 | 0.08 - 1.71 | 0.11 – 0.35 | 0.3-1.0 | 12.5-24.5 | 22.3-46.5 | | |
| | | SD | 0.25 | 0.02 | 0.05 | 0.03 | 0.99 | 1.58 | | |
| NDZ | 14 | Mean | 6.3 | 0.19 | 0.3 | 0.7 | 16.8 | 45.9 | 35.7 | 21 |
| | | Range | 5.0-7.5 | 0.07-0.57 | 0.17-0.39 | 0.3-1.0 | 11.4-26.9 | 24.3-64.8 | | |
| | | SD | 0.45 | 0.06 | 0.03 | 0.1 | 1.3 | 2.2 | | |
| CDZ | 14 | Mean | 6.4 | 0.24 | 0.33 | 0.9 | 18.1 | 42.9 | 35.7 | 57 |
| | | Range | 4.9-8.5 | 0.06-0.84 | 0.19-0.55 | 0.3-3.2 | 12.3-25.8 | 30.5-58.0 | | |
| | | SD | 0.5 | 0.04 | 0.07 | 0.08 | 1.7 | 2 | | |
| SDZ | 48 | Mean | 6.9 | 0.39 | 0.36 | 0.9 | 14.2 | 43.6 | 13.8 | 28 |
| | | Range | 5.1-8.8 | 0.07-1.48 | 0.21-0.55 | 0.3-2.4 | 7.8-21.2 | 16.6-102.3 | | |
| | | SD | 0.65 | 0.01 | 0.04 | 0.25 | 0.75 | 1.3 | | |
| STZ | 50 | Mean | 5.5 | 0.21 | 0.39 | 1 | 22.4 | 58.6 | 26 | 14 |
| | | Range | 4.7-7.5 | 0.06-0.59 | 0.25-0.62 | 0.3-3.5 | 10.1-39.6 | 20.8-284.0 | | |
| | | SD | 0.3 | 0.03 | 0.05 | 0.2 | 0.65 | 1.65 | | |
| NTZ | 17 | Mean | 5.8 | 0.26 | 0.41 | 0.7 | 23.8 | 53.3 | 35.3 | 0 |
| | | Range | 4.8-6.9 | 0.04-0.63 | 0.24-0.64 | 0.2-1.2 | 18.1-28.8 | 33.3-72.3 | | |
| | | SD | 0.35 | 0.1 | 0.03 | 0.12 | 1.1 | 0.9 | | |
| HZ | 45 | Mean | 5.4 | 0.1 | 0.49 | 1.4 | 24 | 62.1 | 20 | 36 |
| | | Range | 4.7-7.6 | 0.02-0.4 | 0.28-0.74 | 0.3-4.5 | 12.7-45.4 | 36.3-94.5 | | |
| | | SD | 0.4 | 0.04 | 0.08 | 0.3 | 2 | 0.6 | | |
| CZ | 16 | Mean | 5.7 | 0.21 | 0.35 | 0.7 | 27.9 | 60.6 | 50 | 38 |
| | | Range | 4.5-6.4 | 0.04-0.73 | 0.17-0.54 | 0.4-1.2 | 16.5-51.3 | 40.5-90.3 | | |
| | | SD | 0.2 | 0.07 | 0.04 | 0.14 | 2.8 | 1.15 | | |
| Total | 244 | Mean | 6.3 | 0.29 | 0.36 | 0.9 | 19.8 | 50.8 | 34 | 30 |
| | | Range | 4.5-8.8 | 0.02-1.71 | 0.11-0.72 | 0.2-4.5 | 7.8-51.3 | 16.6-284.0 | | |
| | | SD | 0.95 | 0.11 | 0.08 | 0.4 | 1.25 | 1.95 | | |

***n= number of soil and plant sample***

**TABLE 3**

**VARIATION IN Zn CONTENT OF GRAIN AND STRAW OF DIFFERENT RICE GENOTYPES**

| Sl. No. | Genotypes | | Zn (mg $kg^{-1}$) | | | |
|---|---|---|---|---|---|---|
| | | n* | Grain | | Straw | |
| | | | Mean | Range | Mean | Range |
| 1 | Sona | 50 | 18.1 | 12.5-36.1 | 40.2 | 22.3-90.3 |
| 2 | JGL | 17 | 19.1 | 7.9-33.3 | 44.5 | 25.2-75.7 |
| 3 | MTU-1001 | 15 | 17.3 | 8.9-27.9 | 45.1 | 24.3-75.3 |
| 4 | Jyothi | 15 | 22.4 | 10.5-51.3 | 52.6 | 17.5-90.7 |
| 5 | MTU-1010 | 11 | 20.4 | 11.4-26.0 | 57.5 | 33.8-79.8 |
| 6 | Intaan | 10 | 19.8 | 14.4-27.3 | 58.4 | 39.8-87.5 |
| 7 | Jaya | 9 | 22.7 | 13.8-29.3 | 61.8 | 41.8-85.0 |
| 8 | BR-2655 | 8 | 16.8 | 12.9-26.2 | 45.4 | 22.8-89.5 |
| 9 | Rajamudi | 7 | 14.6 | 12.2-17.6 | 53.9 | 40.3-75.5 |

*Table 3 Continues. . . .*

| Sl. No. | Genotypes | n* | Zn (mg kg$^{-1}$) | | | |
|---|---|---|---|---|---|---|
| | | | Grain | | Straw | |
| | | | Mean | Range | Mean | Range |
| 10 | Thanu | 7 | 16 | 9.1-29.4 | 46.3 | 24.8-66.3 |
| 11 | IR-64 | 6 | 15.4 | 11.5-18.5 | 27.8 | 16.6-37.6 |
| 12 | MO-4 | 6 | 33.2 | 25.2-39.2 | 70.4 | 55.1-90.3 |
| 13 | Doddige | 6 | 22.1 | 18.1-24.8 | 49.7 | 33.3-65.8 |
| 14 | Thunga | 6 | 21.3 | 16.3-25.8 | 55.5 | 46.8-62.8 |
| 15 | Champaka | 5 | 23.5 | 16.5-30.8 | 48.5 | 40.5-60.8 |
| 16 | Sana Batta | 3 | 13.1 | 12.2-14.0 | 56.2 | 51.8-61.3 |
| 17 | Abhilashu | 3 | 22 | 16.2-25.8 | 45.3 | 38.8-50.5 |
| 18 | KRH-2 | 3 | 14.4 | 11.2-16.4 | 50.7 | 41.3-62.1 |
| 19 | Rasi | 2 | 17.6 | 16.5-18.8 | 83.4 | 68.3-98.6 |
| 20 | Ankush | 2 | 11.1 | 9.0-13.2 | 34.8 | 24.7-44.8 |
| 21 | KCP-1 | 2 | 21.4 | 15.4-27.5 | 57.6 | 25.6-89.5 |
| 22 | KMP-150 | 2 | 12.8 | 12.0-13.5 | 19.4 | 18.5-20.3 |
| 23 | Hemavati | 2 | 22 | 20.1-23.9 | 45.8 | 36.0-55.5 |
| 24 | Annekal Batta | 2 | 17.6 | 17.3-17.8 | 48.8 | 40.8-56.8 |
| 25 | PUBM-8 | 2 | 27.5 | 20.7-34.4 | 62.5 | 38.7-86.3 |
| 26 | Sharavati | 2 | 28.7 | 24.1-33.3 | 74.4 | 54.3-94.5 |
| 27 | IET-7191 | 2 | 31.5 | 27.5-35.5 | 81.5 | 78.8-84.3 |
| 28 | CTH-1 | 2 | 18.7 | 12.7-24.8 | 53.8 | 36.3-71.3 |
| 29 | CTH-3 | 2 | 18.9 | 14.3-23.6 | 72.1 | 68.1-76.0 |
| 30 | Aryza-6444 | 1 | 12.3 | - | 102.3 | - |
| 31 | Sonalam | 1 | 18 | - | 39.3 | - |
| 32 | Lokanatha | 1 | 10.1 | - | 20.8 | - |
| 33 | Jeerge Sanna | 1 | 39.6 | - | 63.8 | - |
| 34 | Siri 1253 | 1 | 24.8 | - | 56 | - |
| 35 | Basmati | 1 | 27.8 | - | 80.2 | - |
| 36 | Siddhagiri-2 | 1 | 26.6 | - | 59.3 | - |
| 37 | IET-9926 | 1 | 22.8 | - | 63.5 | - |
| 38 | Warangal | 1 | 14.3 | - | 65.3 | - |
| 39 | IR-20 | 1 | 13.6 | - | 49.5 | - |
| 40 | Holesalu | 1 | 22 | - | 42.3 | - |
| 41 | Uddara | 1 | 16.6 | - | 43.3 | - |
| 42 | Kesari Batta | 1 | 13.6 | - | 59.3 | - |
| 43 | Kirwana | 1 | 27.6 | - | 47.1 | - |
| 44 | Billi Batta | 1 | 16.8 | - | 55.3 | - |
| 45 | NLR | 1 | 11.6 | - | 18.9 | - |
| 46 | Raksha | 1 | 7.8 | - | 30.2 | - |
| 47 | KHP-9 | 1 | 21.4 | - | 40.8 | - |
| 48 | BKBM-23 | 1 | 23.4 | - | 41.4 | - |
| 49 | KHP-2 | 1 | 24.5 | - | 46.8 | - |
| 50 | KHP-5 | 1 | 25.9 | - | 70.8 | - |
| 51 | Prakash | 1 | 21.2 | - | 38.6 | - |
| 52 | Nagamani | 1 | 13.3 | - | 55.3 | - |
| 53 | GK-5003 | 1 | 15.8 | - | 48.3 | - |
| 54 | Putta Batta | 1 | 45.4 | - | 73.5 | - |
| 55 | AVT-2 | 1 | 20.5 | - | 59.8 | - |
| 56 | KHRS-28 | 1 | 19.2 | - | 73.7 | - |
| 57 | Thirthalli | 1 | 21 | - | 60.3 | - |
| 58 | KHP-10 | 1 | 23 | - | 80 | - |
| 59 | KMP-148 | 1 | 31.6 | - | 81.8 | - |
| 60 | BKV | 1 | 33.5 | - | 85.3 | - |
| 61 | Phalguna | 1 | 37.4 | - | 74.3 | - |
| 62 | Gangana | 1 | 10.3 | - | 24.3 | - |
| 63 | KMP-149 | 1 | 18.2 | - | 16.2 | - |
| 64 | Doddi (Red) | 1 | 37.9 | - | 79.5 | - |
| | **Total** | **244** | **19.8** | **7.9-51.3** | **50.8** | **16.6-284.0** |

**** n =Number of sample***

**TABLE 4**
**CATEGORIZATION OF RICE GENOTYPES BASED ON ITS ZN CONTENT IN GRAIN AND STRAW**

| Sl. no. | Grain | | | | | | Straw | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | < 20 mg Zn kg$^{-1}$ | | 20-30 mg Zn kg$^{-1}$ | | > 30 mg Zn kg$^{-1}$ | | < 50 mg Zn kg$^{-1}$ | | 50-80 mg Zn kg$^{-1}$ | | > 80 mg Zn kg$^{-1}$ | |
| | Genotype | mg kg$^{-1}$ | Genotype | mg kg$^{-1}$ | Genotype | mg kg$^{-1}$ | Genotype | mg kg$^{-1}$ | Genotype | mg kg$^{-1}$ | Genotype | mg kg$^{-1}$ |
| 1 | Raksha | 7.8 | MTU-1010 | 20.4 | IET-7191 | 31.5 | KMP-149 | 16.2 | KRH-2 | 50.7 | Basmati | 80.2 |
| 2 | Lokanatha | 10.1 | AVT-2 | 20.5 | KMP-148 | 31.6 | NLR | 18.9 | Jyothi | 52.6 | IET-7191 | 81.5 |
| 3 | Gangana | 10.3 | Thirthalli | 21 | MO-4 | 33.2 | KMP-150 | 19.4 | CTH-1 | 53.8 | KMP-148 | 81.8 |
| 4 | Ankush | 11.1 | Prakash | 21.2 | BKV | 33.5 | Lokanatha | 20.8 | Rajamudi | 53.9 | Rasi | 83.4 |
| 5 | NLR | 11.6 | Thunga | 21.3 | Phalguna | 37.4 | Gangana | 24.3 | Billi Batta | 55.3 | BKV | 85.3 |
| 6 | Aryza-6444 | 12.3 | KCP-1 | 21.4 | Doddi (Red) | 37.9 | IR-64 | 27.8 | Nagamani | 55.3 | Aryza-6444 | 102.3 |
| 7 | KMP-150 | 12.8 | KHP-9 | 21.4 | Jeerge Sanna | 39.6 | Raksha | 30.2 | Thunga | 55.5 | | |
| 8 | Sana Batta | 13.1 | Abhilashu | 22 | Putta Batta | 45.4 | Ankush | 34.8 | Siri 1253 | 56 | | |
| 9 | Nagamani | 13.3 | Hemavati | 22 | | | Prakash | 38.6 | Sana Batta | 56.2 | | |
| 10 | IR-20 | 13.6 | Holesalu | 22 | | | Sonalam | 39.3 | MTU-1010 | 57.5 | | |
| 11 | Kesari Batta | 13.6 | Doddige | 22.1 | | | Sona | 40.2 | KCP-1 | 57.6 | | |
| 12 | Warangal | 14.3 | Jyothi | 22.4 | | | KHP-9 | 40.8 | Intaan | 58.4 | | |
| 13 | KRH-2 | 14.4 | Jaya | 22.7 | | | BKBM-23 | 41.4 | Siddhagiri-2 | 59.3 | | |
| 14 | Rajamudi | 14.6 | IET-9926 | 22.8 | | | Holesalu | 42.3 | Kesari Batta | 59.3 | | |
| 15 | IR-64 | 15.4 | KHP-10 | 23 | | | Uddara | 43.3 | AVT-2 | 59.8 | | |
| 16 | GK-5003 | 15.8 | BKBM-23 | 23.4 | | | JGL | 44.5 | Thirthalli | 60.3 | | |
| 17 | Thanu | 16 | Champaka | 23.5 | | | MTU-1001 | 45.1 | Jaya | 61.8 | | |
| 18 | Uddara | 16.6 | KHP-2 | 24.5 | | | Abhilashu | 45.3 | PUBM-8 | 62.5 | | |
| 19 | BR-2655 | 16.8 | Siri-1253 | 24.8 | | | BR-2655 | 45.4 | IET-9926 | 63.5 | | |
| 20 | Billi Batta | 16.8 | KHP-5 | 25.9 | | | Hemavathi | 45.8 | Jeerge Sanna | 63.8 | | |
| 21 | MTU-1001 | 17.3 | Siddhagiri-2 | 26.6 | | | Thanu | 46.3 | Warangal | 65.3 | | |
| 22 | Rasi | 17.6 | PUBM-8 | 27.5 | | | KHP-2 | 46.8 | MO-4 | 70.4 | | |
| 23 | Annekal Batta | 17.6 | Kirwana | 27.6 | | | Kirwana | 47.1 | KHP-5 | 70.8 | | |
| 24 | Sonalam | 18 | Basmati | 27.8 | | | GK-5003 | 48.3 | CTH-3 | 72.1 | | |
| 25 | Sona | 18.1 | Sharavati | 28.7 | | | Champaka | 48.5 | Putta Batta | 73.5 | | |
| 26 | KMP-149 | 18.2 | | | | | Annekal Batta | 48.8 | KHRS-28 | 73.7 | | |
| 27 | CTH-1 | 18.7 | | | | | IR-20 | 49.5 | Phalguna | 74.3 | | |
| 28 | CTH-3 | 18.9 | | | | | Doddige | 49.7 | Sharavati | 74.4 | | |
| 29 | JGL | 19.1 | | | | | | | Doddi (Red) | 79.5 | | |
| 30 | KHRS-28 | 19.2 | | | | | | | KHP-10 | 80 | | |
| 31 | Intaan | 19.8 | | | | | | | | | | |

### 3.3.2 Grain Zn content:

Based on Zn content of rice grain, sixty four rice genotypes were categorized as <20 mg Zn $kg^{-1}$, 20-30 mg Zn $kg^{-1}$ and >30 mg Zn $kg^{-1}$. The rice genotypes Raksha, Lokanatha, Gangana, Ankush, NLR, Aryza-6444, KMP-150, Sana Batta, Nagamani, IR-20, Kesari Batta, Warangal, KRH-2, Rajamudi, IR-64, GK-5003, Thanu, Uddara, BR-2655, Billi Batta, MTU-1001, Rasi, Annekal Batta, Sonalam, Sona, KMP-149, CTH-1, CTH-3, JGL, KHRS-28 and Intaan has been categorized under <20 mg Zn $kg^{-1}$ grain (Table 4). Whereas MTU-1010, AVT-2, Thirthalli, Prakash, Thunga, KCP-1, KHP-9, Abhilashu, Hemavati, Holesalu, Doddige, Jyothi, Jaya, IET-9926, KHP-10, BKBM-23, Champaka, KHP-2, Siri-1253, KHP-5, Siddhagiri-2, PUBM-8, Kirwana, Basmati and Sharavati were categorized under 20-30 mg Zn $kg^{-1}$ grain. The rice genotypes IET-7191, KMP-148, MO-4, BKV, Phalguna, Doddi (Red), Jeerge Sanna, and Putta Batta were categorized as >30 mg Zn $kg^{-1}$.

Among 64 rice genotypes collected from eight ACZ of Karnataka, the highest grain Zn content was observed in Putta Batta (45.4 mg $kg^{-1}$) while the lowest was observed in Raksha (7.8 mg $kg^{-1}$) as presented in Table 4.

### 3.3.3 Straw Zn content:

Based on Zn content of rice straw, sixty four rice genotypes were categorized as <50 mg Zn $kg^{-1}$, 50-80 mg Zn $kg^{-1}$ and >80 mg Zn $kg^{-1}$. Accordingly, KMP-149, NLR, KMP-150, Lokanatha, Gangana, IR-64, Raksha, Ankush, Prakash, Sonalam, Sona, KHP-9, BKBM-23, Holesalu, Uddara, JGL, MTU-1001, Abhilashu, BR-2655, Hemavati, Thanu, KHP-2, Kirwana, GK-5003, Champaka, Annekal Batta, IR-20 and Doddige have been categorized under <50 mg Zn $kg^{-1}$ straw (Table 4). Whereas KRH-2, Jyothi, CTH-1, Rajamudi, Billi Batta, Nagamani, Thunga, Siri-1253, Sana Batta, MTU-1010, KCP-1, Intaan, Siddhagiri-2, Kesari Batta, AVT-2, Thirthalli, Jaya, PUBM-8, IET-9926, Jeerge Sanna, Warangal, MO-4, KHP-5, CTH-3, Putta Batta, KHRS-28, Phalguna, Sharavati, Doddi (Red) and KHP-10 categorized under 50-80 mg Zn $kg^{-1}$ straw. The rice genotypes Basmati, IET-7191, KMP-148, Rasi, BKV and Aryza-6444 were categorized under >80 mg Zn $kg^{-1}$ straw.

Among 64 rice genotype collected from eight ACZ of Karnataka, the highest straw Zn content was observed in Aryza-6444 (102.3 mg $kg^{-1}$) while the lowest straw Zn content was observed in KMP-149 (16.2 mg $kg^{-1}$) as presented in Table 4.

### 3.4 Relationship of soil pH, OC and DTPA-Zn with Zn content in grain and straw:

The relationship of soil pH, OC and DTPA-Zn with Zn content in grain and straw of selected rice genotypes were established by determining the correlation coefficient values (Table 5). The correlation analysis revealed that soil pH had positive significant correlation with EC (r=0.690**) but negative significant correlation with OC (r= -0.496**), DTPA-Zn (r= -0.202**), grain Zn (r= -0.470**) and straw Zn (r= -0.451**). The correlation matrix revealed that EC had negative significant correlation with OC (r= -0.364**), DTPA-Zn (r= -0.163*), grain Zn (r= -0.315**) and straw Zn (r= -0.290**). The correlation data shows that OC had positive significant correlation with DTPA-Zn (r= 0.650**), grain Zn (r= 0.422**) and straw Zn (r= 0.342**). The correlation data also revealed that DTPA-Zn had positive significant correlation with grain Zn (r= 0.377**) and straw Zn (r= 0.281**). It was also noticed that grain Zn had positive significant correlation with straw Zn (r= 0.541**).

**TABLE 5**
**CORRELATION MATRIX OF SOIL pH, EC, Zn CONTENT OF SOIL, GRAIN AND STRAW**

| Correlations Matrix | | | | | | |
|---|---|---|---|---|---|---|
| **Variables** | **Soil pH** | **EC** | **OC** | **DTPA-Zn** | **Grain Zn** | **Straw Zn** |
| **Soil pH** | - | 0.690** | -0.496** | - 0.202** | - 0.470** | - 0.451** |
| **EC** | | - | -0.364** | - 0.163* | - 0.315** | - 0.290** |
| **OC** | | | - | 0.650** | 0.422** | 0.342** |
| **DTPA-Zn** | | | | - | 0.377** | 0.281** |
| **Grain Zn** | | | | | - | 0.541** |
| **Straw Zn** | | | | | | - |

The $R^2$ values of the regression equation between soil pH and grain Zn content of fifteen rice genotypes ranged from 0.023 to 0.510 (Table 6) contributing about 2.3 per cent to 51.0 per cent towards grain Zn content whereas $R^2$ values ranged from 0.062 to 0.867 between soil pH and straw Zn content contributing about 6.2 per cent to 86.7 per cent towards straw Zn content through soil pH. The $R^2$ values of regression equation between OC and grain Zn content of rice genotypes ranged from 0.029 to 0.823 contributing about 2.9 to 82.3per cent towards grain Zn content while $R^2$ values between OC and straw Zn content of rice

genotypes ranged from 0.114 to 0.605 contributing about 11.4 to 60.5 per cent towards straw Zn content through OC content of soil. The $R^2$ values of regression equation between DTPA-Zn and grain Zn content of rice genotypes ranged from 0.011 to 0.806 contributing about 1.1 to 80.6 per cent towards grain Zn content while $R^2$ values ranged from 0.086 to 0.772 between DTPA-Zn and straw Zn content of rice genotypes contributing about 8.6 to 77.2 per cent towards straw Zn content through DTPA-Zn of soil.

**TABLE 6**

**RELATIONSHIP OF Zn CONTENT OF RICE GRAIN AND STRAW WITH SOIL pH AND DTPA-Zn IN SOIL**

| Sl. No. | Genotype | Regression equations (x = soil pH) | $R^2$ value | Regression equations (x = DTPA-Zn) | $R^2$ value | Regression equations (x = Organic carbon) | $R^2$ value |
|---|---|---|---|---|---|---|---|
| 1 | Sona | Grain Zn = -2.302x + 34.87 | 0.35 | Grain Zn = 3.356x + 15.56 | 0.065 | Grain Zn = 24.359x + 11.68 | 0.36 |
| | | Straw Zn = -4.914x + 76.02 | 0.242 | Straw Zn = 13.02x + 30.40 | 0.15 | Straw Zn = 48.801x + 27.35 | 0.219 |
| 2 | MTU-1001 | Grain Zn = -2.659x + 33.89 | 0.441 | Grain Zn = 4.511x + 13.85 | 0.133 | Grain Zn = 24.839x + 09.23 | 0.288 |
| | | Straw Zn = -6.222x + 83.82 | 0.237 | Straw Zn = 13.61x + 34.56 | 0.119 | Straw Zn = 49.830x + 28.80 | 0.114 |
| 3 | MTU-1010 | Grain Zn = -4.786x + 48.02 | 0.322 | Grain Zn = 11.59x + 11.39 | 0.213 | Grain Zn = 30.012x + 8.311 | 0.46 |
| | | Straw Zn = -8.819x + 108.3 | 0.18 | Straw Zn = 31.60x + 32.90 | 0.261 | Straw Zn = 45.341x + 39.21 | 0.173 |
| 4 | JGL | Grain Zn = -2.414x + 33.96 | 0.134 | Grain Zn = 3.621x + 14.71 | 0.369 | Grain Zn = 34.737x + 5.558 | 0.406 |
| | | Straw Zn = -8.668x + 97.99 | 0.284 | Straw Zn = 6.279x + 36.95 | 0.181 | Straw Zn = 52.047x + 24.26 | 0.149 |
| 5 | Jaya | Grain Zn = -2.507x + 37.17 | 0.11 | Grain Zn = 0.736x + 21.83 | 0.011 | Grain Zn = 15.9x + 16.058 | 0.121 |
| | | Straw Zn = -4.554x + 88.10 | 0.062 | Straw Zn = 4.965x + 56.16 | 0.086 | Straw Zn = 52.874x + 39.78 | 0.23 |
| 6 | Jyothi | Grain Zn = -6.113x + 58.92 | 0.228 | Grain Zn = 6.289x + 15.32 | 0.169 | Grain Zn = 46.893x + 2.959 | 0.238 |
| | | Straw Zn = -21.38x + 180.3 | 0.504 | Straw Zn = 14.40x + 36.42 | 0.16 | Straw Zn = 91.744x + 14.59 | 0.164 |
| 7 | Intaan | Grain Zn = -0.699x + 23.84 | 0.023 | Grain Zn = 3.212x + 16.57 | 0.236 | Grain Zn = 7.1324x + 16.70 | 0.029 |
| | | Straw Zn = -4.449x + 83.97 | 0.065 | Straw Zn = 14.42x + 43.78 | 0.337 | Straw Zn = 75.553x + 25.34 | 0.231 |
| 8 | BR-2655 | Grain Zn = -0.977x + 23.10 | 0.073 | Grain Zn = 3.286x + 13.98 | 0.108 | Grain Zn = 21.429x + 8.719 | 0.195 |
| | | Straw Zn = -10.68x + 114.1 | 0.346 | Straw Zn = 33.41x + 16.73 | 0.445 | Straw Zn = 182.57x - 23.53 | 0.56 |
| 9 | Thanu | Grain Zn = -3.198x + 38.36 | 0.51 | Grain Zn = 5.012x + 10.70 | 0.806 | Grain Zn = 42.582x + 0.346 | 0.823 |
| | | Straw Zn = -10.65x + 120.6 | 0.867 | Straw Zn = 7.354x + 38.48 | 0.266 | Straw Zn = 67.859x + 21.305 | 0.32 |
| 10 | Rajamudi | Grain Zn = -1.115x + 21.71 | 0.222 | Grain Zn = 2.765x + 12.85 | 0.103 | Grain Zn = 27.02x + 5.617 | 0.264 |
| | | Straw Zn = -8.270x + 106.3 | 0.439 | Straw Zn = 19.18x + 41.46 | 0.179 | Straw Zn = 133.16x + 9.421 | 0.23 |
| 11 | Thunga | Grain Zn = -3.693x + 42.55 | 0.238 | Grain Zn = 13.50x + 10.95 | 0.7 | Grain Zn = 99.12x - 16.544 | 0.625 |
| | | Straw Zn = -4.741x + 83.26 | 0.178 | Straw Zn = 21.05x + 39.57 | 0.772 | Straw Zn = 153.75x - 3.186 | 0.605 |
| 12 | IR-64 | Grain Zn = -0.784x + 21.25 | 0.147 | Grain Zn = 5.832x + 9.810 | 0.621 | Grain Zn = 11.41x + 10.844 | 0.461 |
| | | Straw Zn = -4.826x + 64.08 | 0.764 | Straw Zn = 14.34x + 14.15 | 0.515 | Straw Zn = 31.125x + 15.487 | 0.472 |
| 13 | MO-4 | Grain Zn = -3.344x + 50.75 | 0.109 | Grain Zn = 23.80x + 19.59 | 0.593 | Grain Zn = 58.305x + 14.526 | 0.806 |
| | | Straw Zn = -8.651x + 115.8 | 0.077 | Straw Zn = 82.52x + 23.28 | 0.75 | Straw Zn = 121.33x + 31.557 | 0.367 |
| 14 | Doddige | Grain Zn = -3.785x + 44.11 | 0.36 | Grain Zn = 12.69x + 16.52 | 0.697 | Grain Zn = 28.006x + 13.467 | 0.577 |
| | | Straw Zn = -25.26x + 196.5 | 0.817 | Straw Zn = 56.99x + 24.62 | 0.715 | Straw Zn = 108.65x + 16.181 | 0.442 |
| 15 | Champaka | Grain Zn = -12.13x + 97.39 | 0.377 | Grain Zn = 17.38x + 8.363 | 0.718 | Grain Zn = 30.491x + 11.437 | 0.447 |
| | | Straw Zn = -23.56x + 192.0 | 0.7 | Straw Zn = 19.22x + 31.82 | 0.432 | Straw Zn = 35.16x + 34.657 | 0.292 |

## IV. DISCUSSION

### 4.1 Zn content in soils:

The results as presented in Table 2 revealed that there was a wide variation in DTPA-Zn content of the collected soil samples across eight ACZ of Karnataka. The DTPA-Zn content of all the soil samples ranged from 0.2 to 4.5 mg $kg^{-1}$ with a mean of 0.9 mg $kg^{-1}$. This variation could be attributed to the differences in physical and chemical properties of the collected soils. The soils, collected from different ACZ, were mainly characterized on the basis of types of soil, cropping system, amount of rainfall and management practices. The different types of soil have different nutrient availability due to difference in soil properties and mainly influenced by management practices and amount of rainfall since they have direct role in Zn availability in soils. This is in accordance with the result reported by Sidhu and Sharma (2010) who stated that wide variation in DTPA-Zn which was ranged from 0.04 to 8.60 mg $kg^{-1}$ with a mean of 1.0 mg $kg^{-1}$ across different ACZ of Indo-Gangetic Plain (IGP) of India was due to differences in soil characteristics and management practices. The large variation of DTPA Zn content in different major soil orders of India was also reported by Katyal and Sharma (1991) who stated that DTPA Zn was highest in Mollisols (1.86 ppm) followed by Oxisols (0.86 ppm) > Inceptisols (0.58 ppm) > Alfisols (0.55 ppm) > Entisols (0.46 ppm) > Vertisols (0.41 ppm) > Aridisols (0.38 ppm).

A wide variation in DTPA-Zn in four soil series of acid soil representing two eastern states (Orissa and Jharkhand), one northern state (Himachal Pradesh) and one southern state (Kerala) of India was reported by Behera et al. (2011). They observed that DTPA-Zn ranged from 0.04 to 10.8 mg $kg^{-1}$ with a mean of 1.1 mg $kg^{-1}$ across four soil series of India.

Among the eight ACZ of Karnataka, the highest DTPA Zn was observed in HZ (1.4 mg $kg^{-1}$) and lowest was observed in NEDZ (0.6 mg $kg^{-1}$) as mentioned in Table 2. The possible reason for highest DTPA-Zn in the soils of HZ might be due to its low soil pH and high OC content in soils. Whereas, the lowest DTPA-Zn in the soils of NEDZ may be attributed to its high soil pH and low OC content among the different ACZ inspite of receiving highest Zn application i.e. 67 per cent of the soil samples. From the results of the present investigation, it was observed that soil pH and OC were one of the most important soil properties controlling DTPA-Zn content in soil. In general, lower the pH of the soil, higher is the DTPA-Zn in soil or vice versa. This inverse relationship of soil pH and DTPA-Zn was also observed by Eyupoglu et al. (1994). Katyal and Sharma (1991) also reported that DTPA-Zn declined with a rise in soil pH. According to Sidhu and Sharma (2010) deficiency of Zn was more widespread in the Trans-Gangetic Plain where the soils were low in OC and high in pH followed by Upper, Middle, and Lower Plains where the soils were relatively low in pH and high in OC content. The distribution of available Zn in soils was mainly influenced by the physicochemical properties of soils like pH, $CaCO_3$ and organic matter content (Appavu and Sreeramulu 1981). Similarly, according to Rajkumar (1994), available Zn status in red (Alfisols) and black soils (Vertisols) of Karnataka was highly affected by soil pH. DTPA-Zn increased with an increase in OC content and decreased with increasing soil pH as reported by Sharma et al. (2004). Ye et al. (2015) reported that one-way ANOVA showed that soil organic matter and soil pH had a significant influence on available Zn content in soils of Yanqing County, Beijing, China. Soil Zn is usually more available in soils with greater organic matter content (Iratkar et al. 2014). This may be attributed to involvement of organic matter in supplying organic chemicals to the soil solution, which may be served as chelates and increase metal availability to plants (Vega et al. 2004; McCauley et al. 2009).

Among the soil chemical factors, soil pH plays the most important role in Zn solubility in soil solution (Anderson and Christensen 1988). In a pH range between 5.5 and 7.0, Zn concentration in soil solution is decreased by 30 to 45-fold for each unit increase in soil pH, thus increasing a risk for development of Zn deficiency in plants (Marschner 1993). Increasing soil pH stimulates adsorption of Zn to soil constituents (e.g., metal oxides, clay minerals) and reduces desorption of the adsorbed Zn (Cakmak 2008). Increasing soil pH, especially above 6.5, results in decreased extractability and plant availability of soil Zn as reported by Iratkar et al. (2014). Lindsay (1991) reported that the concentration of $Zn^{2+}$ in soil solution is sufficiently high at pH 5.0, about $10^{-4}M$ (6.5 mg $kg^{-1}$). When soil pH increased from 5 to 8, concentration of soil solution $Zn^{2+}$ is reduced 1,000 times and becomes nearly $10^{-10}$ $M$ (approx. 0.007 mg $kg^{-1}$). Rupa and Tomar (1999) also observed a sharp increase in Zn sorption with an increase in pH from 4.25 to 6.75, beyond which almost the entire Zn is sorbed. Consequently, an increase in soil pH is associated with very sharp decrease in concentrations of Zn in plant tissues (Sarkar and Wynkjones 1982; Marschner 1995). This explains and corroborates the results of the present investigation in which soil pH plays a dominant role in plant available Zn content (DTPA-Zn) in soils.

Among the eight ACZ of Karnataka, the highest Zn deficiency in soil was observed in CZ (50 per cent deficiency) although 38 per cent of the soils received Zn application while lowest Zn deficiency was observed in SDZ (13.8 per cent deficiency) although 28 per cent of the soils received Zn application. According to Sakal (2001), about 48 per cent of Indian soils are

deficient in Zn while Zn deficiency in soils of Karnataka is up to the extent of 78 per cent (Singh and Saha 1995). However, only 34 per cent of the collected soil samples from different ACZ of Karnataka were found to be deficient in Zn. This may be mainly attributed to 30 per cent of the collected soil samples received Zn application (Table 2).

### 4.2 Zn content in grain and straw of rice in different ACZ:

The results presented in Table 2, revealed that there was a wide variation in grain Zn content but the difference in mean value was narrow among the eight ACZ of Karnataka. The highest grain Zn content was recorded in CZ (27.9 mg $kg^{-1}$) followed by HZ (24.0 mg $kg^{-1}$) > NTZ (23.8 mg $kg^{-1}$) > STZ (22.4 mg $kg^{-1}$) > CDZ (18.1 mg $kg^{-1}$) > NDZ (16.8 mg $kg^{-1}$) > NEDZ (16.0 mg $kg^{-1}$) > SDZ (14.2 mg $kg^{-1}$).

It was expected that under low soil pH, DTPA-Zn might increase in soil and ultimately increasing in the grain and straw Zn content as many authors have pointed out. However, in the present investigation, this relationship was not observed in some of the ACZ of Karnataka. For instance, the mean grain Zn content was higher in CZ compared to that of HZ. But CZ recorded higher soil pH, lower DTPA-Zn and OC content compared to soil pH, DTPA-Zn content and OC of HZ (Table 2). Whereas, the lowest mean grain Zn content was recorded in SDZ although the soil pH of SDZ was lower than that of NEDZ and mean DTPA-Zn and OC was observed higher in SDZ compared to that of NEDZ. These changes in relationship between soil pH, DTPA-Zn, OC and grain Zn content may be attributed to genotypic variation in grain Zn accumulation. In CZ, most of the collected rice genotypes belong to the >40 mg $kg^{-1}$ grain Zn category whereas most of the collected rice genotypes from HZ belong to the <20 mg $kg^{-1}$ and 20-30 mg $kg^{-1}$ grain Zn category. This may be the reason for higher mean grain Zn content in CZ compared to HZ. Similarly, grain Zn content in most of the collected rice genotypes in SDZ and Sona genotype in NEDZ belongs to the <20 mg $kg^{-1}$ grain Zn category. But the range of grain Zn was higher in NEDZ (12.5-24.5 mg $kg^{-1}$) compared to SDZ (7.8-21.2 mg $kg^{-1}$). This indicates that Sona genotype can accumulate more Zn in grain although lower DTPA-Zn content in soils of NEDZ compared to other genotypes collected from SDZ.

Similarly, HZ recorded the highest (62.1 mg $kg^{-1}$) straw Zn content followed by CZ (60.6 mg $kg^{-1}$) > STZ (58.6 mg $kg^{-1}$) > NTZ (53.3 mg $kg^{-1}$) > NDZ (45.9 mg $kg^{-1}$) > SDZ (43.6 mg $kg^{-1}$) > CDZ (42.9 mg $kg^{-1}$) > NEDZ (34.4 mg $kg^{-1}$). The HZ recorded the lowest soil pH, highest DTPA-Zn and OC content whereas NEDZ recorded highest soil pH and lowest DTPA-Zn and OC. This may be the possible reason for observing highest straw Zn content in HZ and lowest in NEDZ. Moreover, most of the collected rice genotypes from HZ had straw Zn content in 50-80 mg $kg^{-1}$ and >80 mg $kg^{-1}$straw Zn category. Whereas, the Sona rice genotype collected from NEDZ had straw Zn content of <50 mg $kg^{-1}$ straw Zn category.

The above results is in accordance with Wissuwa et al. (2008) who observed that rice genotypes has a much larger effect than Zn fertilization and native soil Zn content for grain Zn concentration under slightly low Zn content whereas under severely low Zn in soil, native soil Zn was the dominant factor to determine Zn concentrations in both grain and straw of different rice genotypes. They also reported that there was a significant genotypic difference in straw Zn concentration under high-Zn upland soil (2.7 mg $kg^{-1}$ DTPA-Zn) in which Jalmagna recorded highest (22.9 mg $kg^{-1}$) straw Zn concentration followed by RIL-507 (22.3 mg $kg^{-1}$) > RIL-597 (18.7 mg $kg^{-1}$) > IR-74 (17.7 mg $kg^{-1}$) > IR-68144 (16.9 mg $kg^{-1}$). Genotypic variation in grain Zn content was also reported by Yang et al. (1998) who reported that grain Zn content was ranged from 8.2 to 95.0 mg $kg^{-1}$ with a mean value of 41.9 mg $kg^{-1}$ among 286 rice genotypes.

### 4.3 Variation among the rice genotypes in Zn content of grain and straw:

Among the different rice genotypes, five most commonly grown genotypes were selected for studying the variation in Zn content of rice grain and straw. Sona genotype was collected in large number (n=50) representing six ACZ among the different rice genotypes followed by JGL (n=17) representing five ACZ, Jyothi (n=15) representing five ACZ, MTU-1001 (n=15) and MTU-1010 (n=11) representing three ACZ each, as shown in Table 3.

The results of the present investigation revealed that there was a wide variation in grain and straw Zn content in different rice genotypes collected from eight ACZ of Karnataka. The grain and straw Zn content for 64 rice genotypes ranged from 7.8 to 51.3 mg $kg^{-1}$ and 16.6 to 284.0 mg $kg^{-1}$ with a mean of 19.8 mg $kg^{-1}$ and 50.8 mg $kg^{-1}$, respectively. This is in accordance with Lee et al. (2008) who reported that Zn content ranged from 10.0 to 33.0 mg $kg^{-1}$ with a mean of 22.8 mg $kg^{-1}$ from germplasm of 246 rice cultivars at International Rice Research Institute (IRRI), Philippines. They also observed that among the genotypes tested, there was approximately a two-fold difference in Zn concentrations, suggesting a genetic potential to increase Zn content in rice grain. Similar results was also reported by Graham et al. (1999) who stated that there were approximately four fold differences in grain Zn contents in 1138 brown rice samples and it ranged from 15.9 – 58.4 mg $kg^{-1}$ suggesting ample variation

for this trait that might be exploited through conventional breeding. Germplasm evaluations for Zn concentrations in rice grain have detected up to four fold genotypic differences (Gregoria 2002).

From the above variation in Zn content, a particular rice genotype can be able to accumulate wide range of Zn in their grain and straw from different soils with different soil properties (soil pH, OC, DTPA-Zn) apart from genotypic variation in grain and straw Zn accumulation among the genotypes. This may be due to the variation in soil pH (ranged from 4.5 to 8.8) and OC content (ranged from 0.11 to 0.74per cent) of collected soil samples from eight ACZ. Moreover, the DTPA-Zn content ranged from 0.2 to 4.5 mg $kg^{-1}$. Due to this variation in soil properties of the collected soil samples, a rice genotype may be able to accumulate wide range of Zn in their plant parts in the present investigation. This also showed the dominant role played by the soil pH, OC and DTPA-Zn in soil in determining their content in rice. This finding was in accordance with Wissuma et al. (2008) who stated that the native soil Zn status was the dominant factor to determine grain and straw Zn concentrations followed by genotype and fertilizer. Depending on the soil Zn status ranging from 0.79 to 2.7 mg $kg^{-1}$, grain Zn concentrations of a single genotype (RIL-597) could range from 8 mg $kg^{-1}$ to 47.0 mg $kg^{-1}$. Straw Zn concentrations ranged from 12.4 to 22.9 mg $kg^{-1}$ across five rice genotypes (Jalmagna, RIL-507, RIL-597, IR-74 and IR-68144) depending on the soil Zn status ranging from 0.97 to 2.7 mg $kg^{-1}$. In the present investigation, a single genotype (Jyothi) could accumulate Zn in grain and straw in a range of 10.5 to 51.3 mg $kg^{-1}$ (upto five-fold) and 17.5 to 90.7 mg $kg^{-1}$ (upto four-fold), respectively depending on the soil Zn status ranging from 0.5 to 3.0 mg $kg^{-1}$. Similarly, the Sona genotype can accumulate grain and straw Zn content upto three-fold (12.5 to 36.1 mg $kg^{-1}$) and to four-fold (22.3 to 90.3 mg $kg^{-1}$), respectively depending on the soil Zn status.

### 4.4 Categorization of rice growing soils for Zn content:

The DTPA-Zn content of soils of eight ACZ selected for the study were well below the general critical limit of 0.6 mg $kg^{-1}$ soil as given by Katyal and Rattan (2003). The results revealed that 34 per cent of the 244 soil samples collected were below the general soil critical limit of Zn (0.6 mg $kg^{-1}$ soil) as mentioned in Table 2. But the critical level of DTPA-Zn for predicting Zn deficiency in soils depends upon the kind of soil as well as crop to be grown. According to Doberman and Fairhust (2000), the critical value of Zn was 0.8 mg $kg^{-1}$ soil for rice, while Katyal and Rattan (2003) reported a general value of 0.6 mg $kg^{-1}$ as critical value for soils of India. Singh et al. (2003) suggested DTPA-Zn values of <0.5 mg $kg^{-1}$ soil for vertisols of Gujarat, <0.7 mg $kg^{-1}$ for vertisols of Madhya Pradesh and <1.2 mg $kg^{-1}$ for red and vertisols of Tamil Nadu as low or critical value. Takkar et al. (1997) reported the critical limits of DTPA-Zn in different soils for rice crop as 0.84 - 1.34 mg $kg^{-1}$ (Black soil), 0.45 - 2.0 mg $kg^{-1}$ (Red and Black soil), 0.60 - 1.0 mg $kg^{-1}$ (Red soil), 0.38 - 0.90 mg $kg^{-1}$ (Alluvial soil) and 0.78 - 0.95 mg $kg^{-1}$ (Tarai and river belt soil). They also reported a wide variation in the range of critical limit of Zn (for the same soil) for rice compared to other crops. This was mainly because of the variation in water management to which the rice crop was subjected and thereby changes in soil pH (Prasad and Power 1997) and the availability of Zn (Lindsay 1991).

Analysis of nearly 2,50,000 soil samples and 25,000 plant samples collected from different states in India showed that 48 per cent of the soil samples and 44 per cent of the plant samples contained inadequate levels of Zn (Takkar et al. 1990 and Singh 2007). According to Pirzadeh et al. (2010), the DTPA-Zn concentration in more than 50 per cent of paddy soils was less than its critical deficiency concentration of 2 mg $kg^{-1}$ in 136 paddy soil samples collected from central and south-west Iran.

### 4.5 Categorization of rice genotypes for Zn content:

Among the 244 rice samples comprising 64 rice genotypes collected from eight ACZ of Karnataka, the highest grain Zn content was observed in Putta Batta (45.4 mg $kg^{-1}$) while the lowest was observed in Raksha (7.8 mg $kg^{-1}$) as shown in Table 4. The highest straw Zn content was observed in Aryza-6444 (102.3 mg $kg^{-1}$) while the lowest was observed in KMP-149 (16.2 mg $kg^{-1}$). The indigenous rice viz. Bhutmuri (34.8 ppm), Danarguri (31.4 ppm) and Daransail (30.1 ppm) showed high Zn content in brown rice among the seventeen genotypes tested as reported by Sardar et al. (2015). In the present investigation, it was observed that there was no single genotype which could accumulate Zn in both grain and straw at maximum level suggesting preferential storage of Zn in grain or straw. This was in accordance with Yang et al. (1998) who reported that some rice genotypes had high concentration of Zn in grain while some genotypes had high concentration of Zn in leaves. This may be due to the physiological differences in uptake capacity from soil and retranslocation efficiency from leaves into grain. Anuradha et al. (2012) also studied 126 accessions in Hyderabad, India including cultivated *indica* and *japonica* rice cultivars, germplasm accessions and wild rice genotypes for Zn concentration in brown rice. Zn concentration in grain ranged from 25.2 to 67.3 ppm in 126 rice accessions and was found highest in wild accessions of rice.

Based on Zn content of rice grain, sixty four rice genotypes were categorized as <20 mg Zn $kg^{-1}$, 20-30 mg Zn $kg^{-1}$ and >30 mg Zn $kg^{-1}$. By considering the above categories, it was found that 48.4 per cent of the collected rice genotypes were categorized

under <20 mg $kg^{-1}$ Zn while 39.1 per cent and 12.5 per cent were categorized under 20-30 and >30 mg $kg^{-1}$ Zn, respectively (Table 4).

Based on Zn content of rice straw, sixty four rice genotypes were categorized as <50 mg Zn $kg^{-1}$, 50-80 mg Zn $kg^{-1}$ and >80 mg Zn $kg^{-1}$. By considering the above categories, it was found that 43.8 per cent of the collected rice genotypes were categorized under <50 mg $kg^{-1}$ Zn while 46.9 per cent and 9.4 per cent were categorized under 50-80 and >80 mg $kg^{-1}$ Zn, respectively (Table 4).

Similar type of categorization of rice grain and straw for its Zn content was attempted by Pirzadeh et al. (2010). According to them, rice grains were classified as definite Zn-deficient grains (less than 10 mg $kg^{-1}$), moderate Zn-deficient grains (very likely deficiency; between 10 and 15 mg $kg^{-1}$), moderate Zn sufficient grains (likely deficiency; between 15 and 20 mg $kg^{-1}$), and Zn-sufficient grains (more than 20 mg $kg^{-1}$). They observed that 40 per cent of the collected rice grain samples were considered to be Zn deficient and 15 per cent as definite Zn deficient. Generally, concentration of Zn in more than half of the rice grains was less than the suggested critical level of 20 mg $kg^{-1}$. A Zn level of 40 mg $kg^{-1}$ was considered as critical level of deficiency for rice straw. Ninety percent of rice straw samples had Zn concentration less than its critical level.

In the present study, it was observed that half of the collected rice genotypes were categorized under low Zn category while very few genotypes come under high Zn category. The significance of this categorization is mainly to identify and selection of genotypes which have the capacity to accumulate more Zn in grain and straw. Cakmak (2008) pointed out that a breeding program aiming at development of new genotypes with high Zn concentration first requires existence of useful genetic variation for Zn accumulation in grain and also identification of a useful genetic variation and the most promising parents among the rice genotypes. Hence, there is a need for identification of rice genotypes which have high Zn accumulation capacity in rice grain.

### 4.6 Relationship of soil pH, OC and DTPA-Zn with Zn content in grain and straw of selected rice genotypes:

There was negative significant correlation between soil pH with OC (r= -0.496**), DTPA-Zn (r= -0.202**), grain Zn (r= -0.470**) and straw Zn (r= -0.451**) as shown in Table 5. This result is in accordance with the findings of Talukdar et al. (2009) who stated that DTPA-Zn recorded significant negative correlation with soil pH. Katyal and Sharma (1991) also reported that the DTPA-Zn declined with a rise in pH based on the linear coefficients of correlation. No significant correlation was observed between soil pH and DTPA Zn although negatively correlated (Sidhu and Sharma 2010). Contradictorily, Behera et al. (2011) observed significant positive correlation between soil pH and DTPA Zn. This may be due to the fact that the collected soil samples were acidic in soil reaction whereas in the present investigation soil pH ranged from 4.6 to 8.8 across different ACZ of Karnataka. The possible reason for negative correlation between soil pH and DTPA Zn, grain Zn, straw Zn may be due to enhanced Zn solubility under lower soil pH and thereby increasing grain and straw Zn content. This corroborates the findings of Katyal and Sharma (1991) who stated that under low soil pH, Zn availability was increased.

Organic carbon had positive significant correlation with DTPA-Zn (r= 0.650**), grain Zn (r=0.422**) and straw Zn (r=0.342**) as shown in Table 5. Dhaneshwar et al. (2016) reported available Zn maintained positive and significant correlation with soil OC but negative and significant correlation with soil pH indicating the availability of Zn decreases with increase pH. Similar results were reported by Sharma et al. (2003), Yadav (2008), Yadav and Meena (2009), Talukdar et al. (2009), Sidhu et al. (2010) and Rozas et al. (2015). The DTPA-Zn was significantly and negatively correlated with pH (r= -0.383**) while positively correlated with OC (r= 0.738**) as reported by Mathur et al. (2006). Mathur et al. (2006) also reported that DTPA-Zn had also positive significant correlation with grain Zn (r= 0.377**) and straw Zn (r= 0.281**). Likewise, grain Zn also noticed positive significant correlation with straw Zn (r= 0.541**). Kumar and Babel (2011) reported that the availability of Zn in wheat grains and straw positively correlated with silt, clay, OC and CEC and negatively correlated with sand, $CaCO_3$ and pH of soils. Grain content of Zn was positively and significantly correlated with DTPA-Zn in soils. A positive and significant correlation of DTPA-Zn with uptake of Zn showed that the availability of Zn to plant depended upon the amount of DTPA-Zn in soils (Chahal et al. 2005).

The $R^2$ values of the regression equation between soil pH and grain Zn content of selected fifteen rice genotypes (based on the number of samples collected) were ranged from 0.023 to 0.510 (Table 6) contributing about 2.3 per cent to 51.0 per cent towards grain Zn content through soil pH. Whereas $R^2$ values ranged from 0.062 to 0.867 contributing about 6.2 per cent to 86.7 per cent towards straw Zn content through soil pH. The $R^2$ values between OC and grain Zn content of rice genotypes were ranged from 0.121 to 0.823 contributing about 12.1 per cent to 82.3 per cent towards grain Zn content through OC. Whereas $R^2$ values ranged from 0.114 to 0.605 contributing about 11.4 per cent to 60.5 per cent towards straw Zn content

through OC. The $R^2$ values between DTPA-Zn and grain Zn content of rice genotypes were ranged from 0.011 to 0.806 contributing about 1.1 per cent to 80.6 per cent towards grain Zn content through DTPA-Zn. Whereas $R^2$ values ranged from 0.086 to 0.772 contributing about 8.6 per cent to 77.2 per cent towards straw Zn content through DTPA-Zn. Generally, the contribution of soil pH and DTPA-Zn towards grain Zn content was lower compared to that of straw Zn content while OC content of soil contributed slightly higher in terms of grain Zn content. This indicates that there may be some other controlling factors in accumulation of Zn in grain.

The results of the present investigation indicated that higher the OC and DTPA-Zn content in soil, higher may be its accumulation in rice plants. This is in accordance with Wissuwa et al. (2008) which stated that compared to low Zn soil, high Zn soil increases the Zn content in rice grain and straw. Feng et al. (2012) reported that results of Classification and Regression Trees (CART) analysis showed that the spatial variation of the Zn content in crop grains was mainly affected by the soil organic matter and soil pH. Simple correlation and regression analysis revealed that soil pH was significantly and negatively correlated with Zn concentration in straw while no significant correlation was found between soil pH and Zn concentration in grain. Zinc concentration in straw were significantly and positively correlated with organic matter while significantly and negatively correlated between grain Zn concentration and organic matter content as reported by Zeng et al. (2011). Correlation and regression model analyzes suggest that pH and total organic carbon have distinct effect on the availability of Zn in paddy soils. The uptake of Zn in rice root is much higher than those in straw and rice grains as reported by Halim et al. (2015). Hamed et al. (2014) also reported that the exchangeable-Zn fraction of Zn in acid and alkaline soils of Iran was negative significantly correlated with soil pH while positive significantly correlated with soil organic matter. But contradictorily, Pirzadeh et al. (2010) observed that there was no significant correlation between soil and plant Zn concentrations which may be due to the fact that many other factors besides soil properties such as climate, farm management, and crop genotype are affecting plant uptake of micronutrients. Similarly, Raskin and Ensley (2000) and Brummer et al. (1988) also reported that metal concentration of the rice straw, hull, and grain were not related to soil metal concentration. Most of the large-scale studies have shown weak correlations between soil and plant concentrations of metals (Dudka et al.1995). It seems that only a small part of the taken-up (0.01–10 per cent) metal is allocated to the grain and thus affects the relationship between grain metal concentration and the soil metal content (Raskin and Ensley 2000).

## V. CONCLUSION

The DTPA-Zn content of soils showed large variations (0.2 to 4.5 mg $kg^{-1}$) across eight ACZ of Karnataka, South India due to differences in soil chemical properties and management practices. The magnitude of Zn deficiency in soils varied widely not only among the ACZ but also within the same ACZ. About 34 per cent of the collected soil samples were below the general soil critical limit of Zn (0.6 mg $kg^{-1}$ soil) inspite of receiving Zn application in 30 per cent of the soil samples. Wide variation of Zn content was observed in 244 rice samples comprising of 64 rice genotypes which ranged from 7.8 to 51.3 mg $kg^{-1}$ in grain and 16.6 to 284.0 mg $kg^{-1}$ in straw. A single genotype (Jyothi) could accumulate Zn in grain and straw in a range of 10.5 to 51.3 mg $kg^{-1}$ and 17.5 to 90.7 mg $kg^{-1}$, respectively depending on the soil Zn status ranging from 0.5 to 3.0 mg $kg^{-1}$ and soil chemical properties suggesting a genetic potential to increase Zn content in rice. The variation in Zn content is mainly influenced by soil pH, DTPA-Zn, OC apart from genotypic variation in grain and straw Zn accumulation among the rice genotypes.

Correlation analysis revealed negative relationship between soil pH and DTPA-Zn, OC, Zn content in grain and straw. However, positive relationship exists between DTPA-Zn, OC and Zn content in grain and straw. The present study provides a means to overcome the problem of low Zn content in rice through proper understanding of the relationship between the Zn content in rice plant and soil chemical properties such as soil pH, DTPA-Zn and OC and adoption of proper management practices accordingly. From the present investigation, it is possible to identify and select the genotypes which have the capacity to accumulate more Zn in grain and straw. The selection of genotypes can be exploited for further traditional breeding programme or selection of Zn fertilizer responsive genotypes to enhance Zn content in rice from the perspectives of nutrition of human and livestock.

## REFERENCES

[1] ACC/SCN (2004) Fifth Report on the World Nutrition Situation. Geneva: United Nations, Administrative Committee on Coordination/Sub-Committee on Nutrition

[2] Alloway BJ (2008) Zinc in Soils and Crop Nutrition. International Zinc Association, pp. 1–135. Brussels, Belgium

[3] Anderson PR, Christensen TH (1988) Distribution coefficient of Cd, Co, Ni and Zn in soils. J Soil Sci 39: 15–22

[4] Anuradha K, Surekha A, Anil KB, Babu AP, Swamy BPM, Longvah T, Sarla N (2012) Evaluating rice germplasm for iron and zinc concentration in brown rice and seed dimensions. J Phytol 4(1): 19-25

[5] Appavu K, Sreeramulu US (1981) Forms of Zn and their distribution in some soil profiles of Tamil Nadu. Madras Agric J 68: 323-324

[6] Barah BC (2005) Dynamic of rice economy in India: emerging scenario and policy options. National Bank for Agriculture and Rural Development, Occasional Paper–47 http://www.nabard.org/fileupload/DataBank/OccasionalPapers/OCper cent2047.pdf

[7] Behera SK, Singh MV, Lakaria BL (2009) Micronutrients deficiencies in Indian soils and their amelioration through fertilization. Indian Farming 59(2): 28-31

[8] Behera SK, Singh MV, Singh KN, Sandeep T (2011) Distribution variability of total and extractable zinc in cultivated acid soils of India and their relationship with some selected soil properties. Geoderma 162(3-4): 242-250

[9] Black RE (2003) Zinc deficiency, infectious disease and mortality in the developing world. J Nutr 133: 1485-1489

[10] Brummer GW, Gerth J, Tiller KG (1988) Reaction kinetics of the adsorption and desorption of nickel, zinc and cadmium by goethite. I. Adsorption and diffusion of metals. J Soil Sci 39(1): 37–51

[11] Cakmak I (2002) Plant nutrition research priorities to meet human needs for food in sustainable ways. Plant Soil 247: 3-24

[12] Cakmak I (2008) Enrichment of cereal grains with zinc: Agronomic and genetic biofortification. Plant Soil 302: 1–17

[13] Chahal DS, Sharma BD, Singh PK (2005) Distribution of forms of zinc and their association with soil properties and uptake in different soil orders in semi-arid soils of Punjab, India. Comm Soil Sci Plant Anal 36: 2857–2874

[14] Chandel G, Banerjee S, See S, Meena R, Sharma DJ, Verulkar SB (2010) Effect of Different Nitrogen Fertilizer Levels and Native Soil Properties on Rice Grain Fe, Zn and Protein Contents. Rice Sci 17(3): 213-227

[15] Cox FR, Kamprath EJ (1972) Micronutrients soil tests. In: Mortvedt JJ, Giordano PM, Lindsay WL (Eds.) Micronutrients in Agriculture. Soil Science Society of America, Madison, WI, pp. 289–315

[16] Dhaneshwar P, Arup S, Pal B (2016) DTPA-Extractable Zinc in rice soils and its availability to rice. Current World Environ 11(2): 662-669

[17] Dobermann A, Fairhurst TH (2000) Nutrient disorders and nutrient management. Potash and Phosphate Institute, Potash and Phosphate Institute of Canada and International Rice Research Institute, Singapore

[18] Dudka S, Poncehr, Hutchinson TC (1995) Current levels of total element concentrations in the surface laver of Sudbury's soils. Sci Total Environ 162:161–172

[19] Eyupoglu F, Kurucu N, Sanisa U (1994) Status of plant available micronutrients in Turkish soils (in Turkish). Annual Report, Report No: R-118. Soil and Fertilizer Research Institute, Ankara, 1994; 25–32

[20] Fageria NK, Baligar VC, Clark RB (2002) Micronutrients in crop production. Advances Agronomy 77: 185-268

[21] Feng J, Jian Z, Xinmin B, Weijian Z (2012) Spatial distribution and controlling factors of heavy metals contents in paddy soil and crop grains of rice-wheat cropping system along highway in East China. Environ Geochem Health 34(5): 605-614

[22] Graham R, Senadhirad, Beebe S, IglesiaS C, Monasterio I (1999) Breeding for micronutrient density in edible portions of staple food crops: conventional approaches. Field Crops Res 60: 57-80

[23] Gregoria GB, Senadhira GB, Mendoza RD, Manigbas NL, Roxasjp, Guerta CQ (2002) Progress in breeding for salinity tolerance and associated abiotic stresses in rice. Field Crops Res 76: 91–101

[24] Halim MA, Majumder RK, Zaman MN (2015) Paddy soil heavy metal contamination and uptake in rice plants from the adjacent area of Barapukuria coal mine, northwest Bangladesh. Arabian J Geosci 8(6): 3391-3401

[25] Hamed F, Hesam A, Habib F, Hossein M (2014) Distribution of zinc and copper fractions in acid and alkaline (highly calcareous) soils of Iran. J Soil Sci Environ Manage 3(1): 6-13

[26] Iratkar AG, Giri JD, Kadam MM, Giri JN, Dabhade MB (2014) Distribution of DTPA extractable micronutrients and their relationship with soil properties in soil of Parsori watershed of Nagpur district of Maharashtra. Asian J Soil Sci 9: 297-299

[27] Jackson ML (1973) Soil chemical analysis. New Delhi: Prentice Hall of India Pvt. Ltd., New Delhi

[28] Katyal JC, Sharma BD (1991) DTPA-extractable and total Zn, Cu, Mn, and Fe in Indian soils and their association with some soil properties. Geoderma 49(1-2): 165-179

[29] Katyal JC, Rattan RK (2003) Secondary and micronutrients: Research gaps and future needs. Fert News 48(4): 9-20

[30] Katyal JC, Vlek FLG (1985) Micronutrients in tropical foods. Ferti Res7: 69-94

[31] Kumar M, Babel AL (2011) Available micronutrient status and their relationship with soil properties of Jhunjhunu Tehsil, District Jhunjhunu, Rajasthan, India. J Agric Sci 3(2): 97-106

[32] Lee JH, Lee KS, Hwang HG, Yang CI, Lee SB, Choi YH, Jeong OY, Virk P (2008) Evaluation of iron and zinc content in rice germplasms. Korean J Breeding Sci 40(2): 101-105

[33] Lindsay WL(1991) Inorganic equilibria affecting micronutrients in soil. In: Mortvedt JJ, Cox FR, Shuman LM, Welch RM (eds.) Micronutrient in agriculture, 2nd ed., Soil Sci Soc America, Inc., Madison, WI, U.S.A.pp 89-112

[34] Lindsay WL, Norvell WA (1978) Development of DTPA soil test for zinc, iron, manganese and copper. Soil Sci Soc Am J 42: 421-428

[35] Liu Z (1991) Characterization of content and distribution of microelements in soils of China. In: Portch S. (ed), International Symposium on Role of Sulphur, Magnesium, and Micronutrients in Balanced Plant Nutrition, Potash and Phosphate Institute of Canada, Hong Kong, China, pp. 54–61

[36] Liu Z, Zhu QQ, Tang LH (1983) Micronutrients in the main soils of China. Soil Sci 135: 40-46

[37] Marschner H (1993) Zinc uptake from soils. In: Robson AD (ed) Zinc in soils and plants, Kluwer, Dordrecht, The Netherlands, pp. 59-77

[38] Marschner H (1995) Mineral nutrition of higher plants, Academic Press, London.

[39] Mathur GM, Deo R, Yadav BS (2006) Status of zinc in irrigated north-west plain soils of Rajasthan. J Indian Soc Soil Sci 54(3): 359-361

[40] McCuley A, Jones C, Jacobsen J (2009) Soil pH and organic matter. Nutrient management modules 8, #4449-8. Montana State University Extension Service, Bozeman, Montana, pp. 1-12

[41] Pirzadeh M, Majid A, Amirhossein K, Schulin R (2010) Micronutrient status of calcareous paddy soils and rice products: implication for human health. Biol Ferti Soils 46(4): 317-322

[42] Prasad R, Power JF (1997) Soil fertility management for sustainable agriculture. CRC Press LLC, Boca Raton, FL, U.S.A. pp 1-356

[43] Rajkumar GR (1994) Studies on forms and distribution of micronutrients in paddy soils of Tungabhadra Project – Karnataka. M. Sc. (Agri.) Thesis, University of Agricultural Sciences., Dharwad

[44] Raskin I, Ensley BD (2000) Phytoremediation of toxic metals: using plants to clean up the environment. Wiley, New York, pp 352

[45] Rozas HS, Marino P, Mercedes E, Pablo AB, Echeverria HE, Nahuel IRC, Juan PM (2015) Available zinc levels in soils of Argentina. Int J Agron Agri Res 7(5): 59-71

[46] Rupa TR, Tomar KP (1999) Zinc desorption kinetics as influenced by pH and phosphorus in soils. Comm Soil Sci Plant Anal 30:1951–1962

[47] Sardar G, Mallick GK, Jana K, Ghosh S (2015) Screening of high iron and zinc rice genotypes in red and lateritic areas of West Bengal. Int J Applied Biores 23: 7-9

[48] Sakal R (2001) Efficient management of micronutrients for sustainable crop production. J Indian Soc Soil Sci 49(4): 593-608

[49] Sarkar AN, Wynjones RG (1982) Effect of rhizosphere pH on the availability and uptake of Fe, Mn and Zn. Plant Soil 66:361–372

[50] Sharma RP, Singh M, Sharma JP (2003) Correlation studies on micronutrients vis-à-vis soil properties in some soils of Nagaur district in semi-arid region of Rajasthan. J Indian Soc Soil Sci 51(4): 522-527

[51] Sharma BD, Arora H, Kumar R, Nayyar VK (2004) Relationships between soil characteristics and total and DTPA-extractable micronutrients in Inceptisols of Punjab. Comm Soil Sci Plant Anal 35(5 & 6): 799-818

[52] Shuman LM (1986) Effect of liming on the distribution of manganese, copper, iron and zinc among the soil fractions. Soil Sci Soc Am J 50: 1236-1240

[53] Sidhu GS, Sharma BD (2010) Diethylenetriaminepentaacetic Acid-Extractable micronutrients status in soil under a rice-wheat system and their relationship with soil properties in different agroclimatic zones of Indo-Gangetic plains of India. Comm Soil Sci Plant Anal 41(1): 29-51

[54] Singh MV, Patel KP, Ramani VP (2003) Crop responses to secondary and micronutrients in swell-shrink soils. Fert News 48(4): 55-68

[55] Sillanpaa M (1990) Micronutrient assessment at the country level: an international study, FAO Soils Bulletin 63. FAO/Finnish International Development Agency, Rome, Italy

[56] Singh MV (2001) Evaluation of micronutrient status in different agro-ecological zones of India. Fert News 46 (2): 25-42

[57] Singh MV, Saha JK (1995) In 26th Progress Report of the All India Coordinated Scheme of micro and secondary-nutrients and pollution elements in soils and plants (1993-94-95) IISS, Bhopal

[58] Soepardi G (1982) The zinc status in Indonesian agriculture. Contrib. Cent. Res. Inst. Food Crops Bogor 68: 10-31

[59] Takkar PN (1996) Micronutrient research and sustainable agricultural productivity in India. J Indian Soc Soil Sci 44: 562-581

[60] Takkar PN, Chhibba IM, Mehta SK (1990) Two decades of micronutrient research in India. Indian Institute of Soil Science, Bhopal. pp.1-210

[61] Takkar PN, Singh MV, Ganeshmurthy AN (1997) Micronutrients and trace elements. In Kanwar JS, Katyal JC (eds.) Plant nutrient needs, Efficiency and Policy issues, 2000-2025, National Academy of Agricultural Sciences, New York. pp 238-264

[62] Talukdar MC, Basumatary A, Dutta SK (2009) Status of DTPA-extractable cationic micronutrients in soils under rice and sugarcane ecosystems of Golaghat district in Assam. J Indian Soc Soil Sci 57(3): 313-316

[63] Vega FA, Covelo EF, Andrade ML, Marcet P (2004) Relationship between heavy metals content and soil properties in minesoils. Analytica Chimica Acta. 524: 141-150

[64] Walkley AJ, Black CA (1934) Estimation of soil organic carbon by the chromic and titration method. Soil Sci 37: 29-38

[65] White JG, Zasoki RJ(1999) Mapping soil micronutrients. Field Crops Res 60:11-26

[66] Wissuwa M, Ismail AM, Graham RD (2008) Rice grain zinc concentrations as affected by genotype, native soil-zinc availability, and zinc fertilization. Plant Soil306: 37-48

[67] World Health Organization (2007) UNICEF India, Children issues. Global Database on child growth and malnutrition in United Nations Administrative Committee on Coordination/Sub-committee on Nutrition, low birth weight, nutrition policy, Paper 18. http://www.who.int/nutgrowthdb/en/.

[68] Yang X, Ye ZQ, Shi CH, Zhu ML, Graham RD (1998) Genotypic differences in concentrations of iron, manganese, copper and zinc in polished rice grains. J Plant Nutr 21(7):1453-1462

[69] Ye H, Shen C, Huang Y, Huang W, Zhang S, Jia X (2015) Spatial variability of available soil microelements in an ecological functional zone of Beijing. Environ Monit Assess 187: 13

[70] Zeng F, Ali S, Zhang H, Ouyang Y, Qiu B, Wu F (2011) The influence of pH and organic matter content in paddy soil on heavy metal availability and their uptake by rice plants. Environ Pollut 159: 84-91.

# Evaluation of the Production Efficiency and Profitability of Groundnut Production in Bwari and Gwagwalada Area Councils of Abuja, Nigeria

Funso Omolayo Alabuja[1]; Hauwa Bako[2]; Beatrice Itoya Oyediji[3]; Joseph Bamidele[4]; Sennuga, S. O.[5*]

[1]Department of Agricultural Economics, Faculty of Agriculture, University of Abuja, FCT, P.M.B. 117, Abuja, Nigeria
[2]Departments of Space Enterprises, National Space Research and Development Agency. Airport Road, P.M.B 437, Abuja, Nigeria.
[3]Department of Agricultural Extension and Rural Development, Faculty of Agriculture University of Ibadan, Nigeria
[4]Faculty of Business and Law, University of Northampton, Waterside Campus, University Drive, Northampton NN1 5PH, United Kingdom
[*5]Department of Agricultural Extension and Rural Sociology, Faculty of Agriculture, University of Abuja, FCT, P.M.B. 117, Abuja, Nigeria
*Corresponding Author

Received:- 03 October 2025/ Revised:- 11 October 2025/ Accepted:- 18 October 2025/ Published: 31-10-2025
Copyright @ 2025 International Journal of Environmental and Agriculture Research
This is an Open-Access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (https://creativecommons.org/licenses/by-nc/4.0) which permits unrestricted Non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

***Abstract—*** *This study assessed the production efficiency and profitability of groundnut farmers in Bwari and Gwagwalada Area Councils of Abuja, Nigeria. Using a multistage sampling technique, 200 respondents were surveyed through structured questionnaires. Descriptive statistics, stochastic frontier production function, and net farm income models were applied for analysis. Results showed that 55.0% of farmers were aged 31–50 years, while 57.55% had 5–15 years of farming experience, reflecting an active and knowledgeable farming population. Education was moderate, with 40.0% having secondary education, and household sizes were large, with 57.5% reporting 6 and above members. The stochastic frontier production function indicated that farm size (0.298, t = 4.14***), seed (0.215, t = 3.16***), and labour (0.176, t = 2.98**) significantly influenced economic efficiency, while fertilizer and capital were not significant. Inefficiency variables indicated that age (–0.112, t = –2.43**), farming experience (–0.158, t = –3.04***), education (–0.092, t = –2.42**), extension contact (–0.185, t = –2.98***), and cooperative membership (–0.132, t = –2.69***) significantly reduced inefficiency, while household size and access to credit were not significant. Profitability analysis confirmed viability, with a gross income of ₦145,500/ha, total cost of ₦52,790.00, and net farm income of ₦92,710.00. The return per naira invested (RNI) was 1.76. Key constraints included high input costs (81.0%), limited credit (74.0%), pest infestation (67.5%), and inadequate extension services (60.0%). Based on the findings, the study recommended the 81.0% of farmers identified high input costs as a major constraint, policies should focus on input subsidies, group purchasing schemes, or improved distribution systems to ensure farmers can access quality seeds, fertilizer, and agrochemicals at lower prices.*

***Keywords— Groundnut production, Economic efficiency, Profitability, Inefficiency variables.***

## I. INTRODUCTION

Groundnut (*Arachis hypogaea L.*) is one of the most important leguminous crops in Nigeria, valued both for domestic consumption and its role in trade. Nigeria ranks among the leading producers of groundnut in Africa, with cultivation concentrated in states such as Kano, Kaduna, Katsina, Bauchi, and Jigawa. The crop provides edible oil, protein-rich food, and serves as a key raw material for confectionery, feed, and vegetable oil industries (FAO, 2021). For rural households, groundnut is a major source of livelihood, ensuring both food security and income generation (Amare *et al.*, 2019; Idu *et al.*, 2025).Beyond nutrition, its economic relevance is evident in its contribution to Nigeria's agricultural GDP and its role in rural employment. Historically, Nigeria was a dominant player in global groundnut exports during the 1960s, though this position weakened with the oil boom, policy neglect, and structural changes in agriculture (Okonkwo & Umeh, 2020; Yunus *et al.*, 2025).Even so,

groundnut remains a crop of strategic importance for industrial growth and poverty reduction.Agronomically, it improves soil fertility through nitrogen fixation, making it crucial in sustaining productivity in semi-arid regions. This dual nutritional, economic, and ecological significance underscores why groundnut continues to receive attention in agricultural development and food security strategies in Nigeria (Adeyemi *et al.,* 2025).

Despite its significance, groundnut production in Nigeria faces persistent challenges that undermine efficiency and profitability. The majority of farmers operate on a small scale, using traditional methods with limited access to improved seeds, fertilizers, and mechanization (Abu *et al.,* 2021; Joel *et al.,* 2025).As a result, yields remain far below global averages. Pest and disease infestations, especially groundnut rosette virus, along with drought and erratic rainfall, further reduce output (Olorunfemi *et al.,* 2018).Weak infrastructure and poor access to storage and markets increase post-harvest losses, while financial and institutional barriers—such as inadequate credit and limited extension services—restrict adoption of modern technologies. Market volatility adds to these problems, as smallholders often lack bargaining power and must sell at unfavourable farm-gate prices (Ogunlela & Ogunlade, 2019; Maisule *et al.,* 2025).The combined effect of these constraints is a productivity–profitability gap: farmers struggle not only to maximize efficient resource use but also to earn sustainable returns. Groundnut's potential for supporting rural incomes and national agricultural growth therefore remains underutilized, and its full economic impact is not being realized.

Although there is growing interest in agricultural efficiency and profitability research in Nigeria, studies that integrate both dimensions for groundnut farming remain scarce. Much of the existing work examines profitability using gross margin or net income analysis, or efficiency using approaches such as Stochastic Frontier Analysis (SFA) and Data Envelopment Analysis (DEA). However, few combine the two to provide a complete picture of farm performance (Shehu *et al.,* 2020; Tanko & Jirgi, 2020). Profitability alone cannot explain how effectively resources are utilized, while efficiency measures without profitability do not reveal the actual economic sustainability of farming activities. Moreover, many studies are region-specific, limiting generalization across Nigeria's diverse agro-ecological zones. Important socio-economic factors such as education, household size, farm experience, and access to credit or extension services are often overlooked, even though they significantly influence both efficiency and profitability outcomes. Given Nigeria's persistent food security challenges and rural poverty, there is a pressing need for a comprehensive evaluation that integrates production efficiency with profitability analysis. By filling this gap, the present study contributes both to the academic literature and to practical discussions on Nigeria's agricultural economy (Olaitan. *et al.,* 2025; Oyediji *et al.,* 2025).

This study aims to evaluate the production efficiency and profitability of Groundnut production in Bwari and Gwagwalada Area Councils of Abuja, Nigeria. To accomplish this, the following objectives are put forward:

a) Describe the socio-economic characteristics of groundnut farmers in the study areas.

b) Estimate the economic efficiency of groundnut production.

c) Determine the determinants of efficiency in groundnut production.

d) Estimate the profitability of groundnut production.

e) Identify the major challenges associated with the production of groundnut in the study areas.

## II. LITERATURE REVIEW

### 2.1 Theoretical Framework:

The theoretical framework of this study is anchored on production economics and efficiency theories, which provide the analytical foundation for examining how groundnut farmers in Nigeria utilize resources and derive profitability from their farming enterprises

One of the main theoretical lenses guiding this study is Farrell's (1957) efficiency theory, which decomposes efficiency into three critical components: technical efficiency, allocative efficiency, and economic efficiency. Technical efficiency refers to the ability of farmers to obtain the maximum possible output from a given set of inputs. Allocative efficiency deals with using inputs in optimal proportions given their prices and marginal productivities, while economic efficiency integrates both technical and allocative efficiency to reflect overall resource use performance. These concepts are particularly relevant in Nigeria, where most groundnut farmers are smallholders who operate under imperfect market conditions, face high transaction costs, and have limited access to extension services, credit, and improved technologies. The framework assumes that deviations from the production frontier represent inefficiencies caused by both farm-level and institutional constraints.

Additionally, the study draws from the profit maximization theory, which emphasizes that farm households aim to maximize net returns from agricultural enterprises (Olawunmi *et al.,* 2025). Within this framework, profitability is assessed by comparing total revenue with total production costs. In the case of groundnut farming, profitability is influenced by factors such as input prices (e.g., seed, fertilizer, labor), market prices of outputs, and the efficiency with which resources are utilized. The profitability framework aligns with studies such as Abubakar & Sule (2021) and Salisu *et al.* (2024), which underscore that while groundnut farming is generally profitable, inefficiencies in production often reduce the magnitude of realized gains. By linking efficiency theory with profitability analysis, this framework enables a comprehensive evaluation of how resource allocation patterns, socio-economic characteristics of farmers, and market dynamics collectively influence outcomes in groundnut production (Mato *et al.,* 2025; Oyotomhe *et al.,* 2025).

### 2.2 Conceptual Framework:

The conceptual framework for this study, exploring the relationship between the independent variables and the dependent variables (production efficiency and profitability indicators of Gross margin and Net farm income) being mediated by the intervening variables. The independent variables in this study are the core factors hypothesized to influence both the production efficiency and profitability of groundnut farming, and these include socio-economic characteristics of age, education level, household size, farming experience, gender, access to extension services, access to credit as well as farm resource use of quantity of seed, fertilizer, pesticides/herbicides, labour (family and hired), and capital invested.

The intervening variables are contextual factors that can mediate influence of independent variables on production outcomes. They include access to climatic factors, pest and disease pressure, policy environment and technology adoption.

## III. MATERIALS AND METHODS

### 3.1 Study Area:

This study was conducted in Bwari and Gwagwalada Area Councils of the Federal Capital Territory (FCT), Abuja, Nigeria. Bwari Area Council lies in the northwestern part of Abuja, covering about 914 km². It shares boundaries with Kaduna and Niger States. The area has a tropical climate with a rainy season from April to October and a dry season from November to March. Annual rainfall ranges between 1,100 mm and 1,600 mm, while average temperatures vary between 21°C and 32°C, creating favourable conditions for legume crops such as groundnut. The soils are predominantly sandy-loam and ferruginous, which support crop cultivation (Adewumi & Omotesho, 2019).

Gwagwalada Area Council is located in the southwestern part of Abuja and spans approximately 1,043 km². Positioned along the Abuja–Lokoja highway, the council enjoys strong market linkages that facilitate the distribution of agricultural produce. It experiences similar climatic conditions to Bwari, with rainfall between 1,200 mm and 1,700 mm annually and temperatures averaging 23°C to 34°C. The soil profile, dominated by sandy-loam, is highly suitable for groundnut production (Oladimeji & Abdulsalam, 2020).

Both councils are predominantly rural, and farming is the main source of livelihood. Farmers cultivate groundnut alongside maize, yam, cassava, and cowpea, with livestock rearing also contributing to household income. Groundnut production is particularly important as a cash crop for local consumption, small-scale oil milling, and animal feed. Proximity to Abuja city provides unique market opportunities, yet farmers face challenges including limited access to modern inputs, fluctuating prices, and pest infestations (Salisu *et al.,* 2024).The selection of Bwari and Gwagwalada is justified by their agricultural relevance, prevalence of smallholder groundnut farmers, and strategic location within the FCT. Their blend of rural agricultural activity and urban market access makes them ideal for evaluating production efficiency and profitability under smallholder conditions (Yusuf *et al.,* 2019).

### 3.2 Population of the Study and Research Design:

The population of this study comprises groundnut farmers in Bwari and Gwagwalada Area Councils of the Federal Capital Territory (FCT), Abuja. These farmers are largely smallholders who cultivate groundnut alongside other staples such as maize, yam, and cassava, relying on both family and hired labour. They were selected because of the councils' prominence in smallholder farming and the importance of groundnut as a cash and food crop in the area (FCT-ADP, 2021).The study employs a descriptive and analytical survey research design. Primary data was collected through structured questionnaires and interviews covering socio-economic characteristics, input use, and returns. Production efficiency was estimated using stochastic frontier analysis (SFA), while profitability will be assessed through gross margin and net farm income. This approach ensures a comprehensive evaluation of both efficiency and profitability of groundnut production in the study area.

### 3.3 Sample Size and Sampling Techniques:

A **multistage sampling technique** was adopted for this study to ensure representativeness and minimize bias in the selection of respondents. In the first stage, two Area Councils were purposively selected from the six councils of the Federal Capital Territory (Abuja Municipal, Bwari, Gwagwalada, Kuje, Kwali, and Abaji). Bwari and Gwagwalada were chosen because of their high concentration of smallholder farmers actively involved in groundnut production, as documented by the Federal Capital Territory Agricultural Development Programme (FCT-ADP, 2021).

In the second stage, wards were randomly selected from each of the councils. From Bwari, five wards including Bwari Central, Igu, Ushafa, Kuduru, and Shere were chosen, while in Gwagwalada, five wards such as Dobi, Zuba, Gwako, Paiko, and Ikwa were selected. This stage was critical in ensuring adequate geographic coverage across the study area.

The third stage involved the selection of farming communities within the sampled wards. Two farming communities were randomly chosen in each ward to capture variations in farming practices. For example, in Dobi ward of Gwagwalada, Dobi and Paikon-Kore communities were included, while in Igu ward of Bwari, Igu and Barangoni communities were selected. This provided a spread across different agricultural zones within each council.

Finally, in the fourth stage, the respondents were selected. Lists of registered groundnut farmers were obtained from farmer cooperatives, extension agents, and ADP offices. From these lists, respondents were randomly drawn using simple random sampling. To ensure balance, 100 farmers were selected from Bwari and 100 from Gwagwalada, making a total of 200 respondents. This sample size was considered adequate to capture variations in socio-economic characteristics, production practices, and outcomes among groundnut farmers in the study area.

### 3.4 Data Collection:

The primary instrument for data collection in this study was a structured questionnaire designed to obtain comprehensive information from groundnut farmers in Bwari and Gwagwalada Area Councils. The questionnaire covered socio-economic characteristics, input use, output levels, production costs, and marketing practices relevant to evaluating efficiency and profitability. To ensure validity and reliability, the instrument was pre-tested through a pilot study involving a small group of groundnut farmers outside the main sample. This exercise helped identify ambiguities and refine the structure and wording of questions, enhancing clarity and relevance to the study objectives. Each questionnaire session lasted about one hour, giving respondents adequate time to provide accurate responses. Trained enumerators administered the questionnaires to guide farmers in understanding the questions and to minimize response errors. This process ensured that the final instrument was well-suited to generating reliable primary data for analyzing groundnut production efficiency and profitability in the study area.

### 3.5 Data Analysis:

The data collected for this study were analyzed using both descriptive and inferential statistical techniques in line with the stated objectives. Descriptive statistics such as frequencies, percentages, and means were applied to address objective (i), which profiled the socio-economic characteristics of groundnut farmers, and objective (v), which identified major production constraints. For objectives (ii) and (iii), the stochastic frontier production function (SFA) was employed to estimate economic efficiency and identify its determinants among groundnut farmers. For objective (iv), the net farm income (NFI) approach was used to estimate costs, returns, and profitability in groundnut production. All analyses were conducted using the Statistical Package for the Social Sciences (SPSS v.24) and Frontier 4.1 software, which provided a robust platform for both descriptive and frontier efficiency analysis.

### 3.6 Model Specification:

#### 3.6.1 Net Farm Income (NFI) Model:

Profitability was estimated using the net farm income (NFI) approach:

$$NFI = TR - TC \quad (1)$$

Where:

- NFI = Net farm income (₦)
- TR = Total revenue (₦)
- TC = Total cost of production (₦)

Depreciation of fixed assets was computed using the straight-line method:

$$D = \frac{P-S}{N} \quad (2)$$

Where:

- D = Depreciation (₦)
- P = Purchase value of asset (₦)
- S = Salvage value (₦)
- N = Useful life of asset (years)

The return per naira invested (RNI) was obtained as:

$$RNI = \frac{NFI}{TC} \quad (3)$$

### 3.6.2 Stochastic Frontier Production Function (SFA):

The SFA was used to analyze objectives (ii). The Cobb-Douglas frontier model is specified as:

$$\text{InY} = \beta_0 + \beta_1 \text{InX}_1 + \beta_2 \text{InX}_2 + \beta_3 \text{InX}_3 + ... + \beta_4 \text{InX}_4 + (V_i - U_i) \quad (4)$$

Where:

- Y = Groundnut output (kg)
- $\beta_0$ = Constant term
- $\mathbf{X_1}$ = Farm size (ha)
- $\mathbf{X_2}$ = Quantity of seed (kg)
- $\mathbf{X_3}$ = Labour used (man-days)
- $\mathbf{X_4}$ = Quantity of agrochemicals (litres)
- **Vi** = Random error outside the farmer's control
- **Ui** = Non-negative inefficiency term

## IV. RESULTS AND DISCUSSION

### 4.1 Socio-Economic Characteristics of Groundnut Farmers:

The results in Table 1 show that 55% of farmers were aged 31–50 years, 25% were above 50, while 20% were 30 years or below. This indicates that most groundnut farmers are within their productive years, which enhances their ability to supply labour and adopt innovations. Rahman and Umar (2019) emphasized that middle-aged farmers are typically more productive, while younger farmers secure generational continuity in agricultural production.

Findings in Table 1 revealed that 57.5% of farmers had 5–15 years of experience, 25% had over 15 years, and 17.5% had less than 5 years. This shows that most farmers possess adequate practical knowledge, enhancing decision-making and risk management. Amaza et al. (2019) noted that farming experience is a crucial determinant of efficiency, as it promotes better input utilization and adaptation to local production challenges, ultimately improving farm productivity.The study revealed that 40% of respondents had secondary education, 27.5% primary, 20% tertiary, while 12.5% had no formal education. This demonstrates that a majority possess at least basic education, which is vital for adopting modern practices. Education enhances farmers' ability to process agricultural information and participate in training programs. Ojo and Jibowo (2018) argued that education directly influences productivity by shaping farmers' responsiveness to new technologies and extension interventions.

Results indicate that 42.5% of respondents had 1–5 members, 37.5% had 6–10, while 20% had more than 10. Household size affects labour supply and dependency ratios, with moderately large households providing farm labour and reducing hired labour costs. Idrisa *et al.* (2022) emphasized that family size plays a significant role in smallholder farming systems, particularly where mechanization is minimal, although very large households may increase consumption burdens.The analysis shows that

45% of farmers received 1–3 extension visits per season, 25% had four or more, while 30% had no contact. Agwu et al. (2018) emphasized that extension interactions help farmers enhance input use efficiency and market awareness. Limited contact among some farmers suggests institutional gaps in service delivery that could affect adoption of improved groundnut practices.

About 42.5% of respondents had cooperative membership of 5–10 years, 35% below 5 years, and 22.5% above 10 years. Bernard and Spielman (2019) found that cooperatives play a central role in reducing transaction costs and enabling smallholders to compete effectively. The prevalence of medium-term membership suggests cooperatives are important, though long-term loyalty remains relatively low in the study area.The results show that 30% of farmers accessed ₦50,000–₦100,000, 27.5% less than ₦50,000, 15% above ₦100,000, while 27.5% had no access. Credit availability is critical for investment in inputs and farm expansion, but access remains limited. Nwaru *et al.* (2021) noted that formal credit is constrained by collateral and high interest rates, compelling many smallholders to depend on informal sources, which often restricts capital availability and limits potential profitability in groundnut farming.

**TABLE 1**

**SOCIO-ECONOMIC CHARACTERISTICS OF GROUNDNUT FARMERS (n = 200)**

| Variable | Freq (n = 200) | Percent |
|---|---|---|
| **Educational level** | | |
| No formal education | 25 | 12.5 |
| Primary school | 55 | 27.5 |
| Secondary school | 80 | 40 |
| Tertiary education | 40 | 20 |
| **Age** | | |
| ≤ 30 years | 40 | 20 |
| 31–50 years | 110 | 55 |
| > 50 years | 50 | 25 |
| **Years of farming Experience** | | |
| < 5 | 35 | 17.5 |
| 5–15 | 115 | 57.5 |
| > 15 | 50 | 25 |
| **Household Size** | | |
| 1–5 persons | 85 | 42.5 |
| 6–10 persons | 75 | 37.5 |
| > 10 persons | 40 | 20 |
| **Cooperative Membership (years)** | | |
| < 5 | 70 | 35 |
| 5–10 | 85 | 42.5 |
| > 10 | 45 | 22.5 |
| **Amount of Credit Received (₦)** | | |
| < ₦50,000 | 55 | 27.5 |
| ₦50,000 – ₦100,000 | 60 | 30 |
| > ₦100,000 | 30 | 15 |
| No Credit Access | 55 | 27.5 |
| **Extension Visits per Season** | | |
| None | 60 | 30 |
| 1–3 | 90 | 45 |
| ≥ 4 | 50 | 25 |

***Source: Field Survey, 2025***

### 4.2 Economic Efficiency and Determinants of Efficiency in Groundnut Production:

The results of the stochastic frontier production function for groundnut production in Table 2 highlight both the productive inputs that significantly influence economic efficiency and the socio-economic variables that either improve or hinder technical performance. The model is divided into three components: production function parameters, inefficiency variables, and diagnostic statistics, each of which provides valuable insights into the determinants of groundnut production efficiency.

### 4.3 Production Function:

The production function results highlight the critical role of land, seed, and labour in driving groundnut output. The constant term ($\beta_0 = 0.842$, $p < 0.01$) was significant, indicating a baseline productivity level. Farm size ($\beta_1 = 0.298$, $p < 0.01$) emerged as a major determinant, confirming that larger cultivated areas enhance output. This finding supports Ogundari and Ojo (2018) and aligns with evidence from Shehu *et al.* (2020), who found landholding size to be a strong determinant of efficiency among Nigerian farmers. Seed input ($\beta_2 = 0.215$, $p < 0.01$) was also significant, demonstrating that improved or sufficient seed use raises productivity, consistent with Amaza and Maurice (2019) and Abdulrahman *et al.* (2023), who emphasized seed quality as a driver of yield growth. Labour ($\beta_3 = 0.176$, $p < 0.01$) showed a positive effect, reflecting the labour-intensive nature of groundnut farming, in line with findings by Amos (2019) and Alabi *et al*. (2018).

In contrast, agrochemical use ($\beta_4 = 0.047$, $t = 1.15$) was not significant, suggesting limited or ineffective application, likely due to cost or lack of knowledge. This result echoes Olarinde (2019) and supports the view of Oyekale and Idjesa (2023) that smallholders often face financial or technical barriers in chemical use.

### 4.4 Inefficiency Variables (Determinants of Efficiency in Groundnut Production):

The inefficiency model reveals socio-economic factors influencing farmer performance. The significant constant term ($Z_0 = 0.564$, $p < 0.01$) confirmed the presence of inefficiency effects. Age ($Z_1 = -0.112$, $p < 0.05$) and farming experience ($Z_2 = -0.158$, $p < 0.01$) reduced inefficiency, suggesting that accumulated knowledge improves resource use, as also observed by Idiong (2020) and Rahman and Umar (2009). Education ($Z_3 = -0.092$, $p < 0.05$) improved efficiency, consistent with Bravo-Ureta and Pinheiro (2019), who reported that human capital enhances adoption of improved practices.Household size ($Z_4 = 0.025$, $t = 0.93$) was not significant, implying that larger households do not necessarily translate into effective farm labour, similar to findings by Binam et al. (2004). However, extension contacts ($Z_5 = -0.185$, $p < 0.01$) and cooperative membership ($Z_6 = -0.132$, $p < 0.01$) significantly reduced inefficiency, emphasizing the role of technical support and collective action, as highlighted by Ajibefun and Daramola (2003) and Uaiene *et al.* (2019). Credit access ($Z_7 = -0.038$, $t = -0.93$) was not significant, likely due to inadequate loan sizes or diversion of funds, consistent with Adeyemo *et al.* (2020) and Okoye *et al.* (2023).

### 4.5 Diagnostic Statistics:

The diagnostic statistics validate the robustness of the model. The variance parameter ($\sigma^2 = 0.084$, $p < 0.01$) confirmed its adequacy, while gamma ($\gamma = 0.743$, $p < 0.01$) showed that 74.3% of output variation was due to inefficiency rather than random noise. This finding aligns with Battese and Coelli (2019) and is consistent with Abdulai and Huffman (2018), who noted that inefficiency strongly explains productivity differences among smallholders. With a mean efficiency score of 0.71 across 200 farmers, the study indicates that producers operate at 71% of potential output, leaving 29% of productivity lost to inefficiencies, echoing similar findings by Kolawole (2024).

**TABLE 2**
**MAXIMUM LIKELIHOOD ESTIMATES RESULTS OF STOCHASTIC FRONTIER PRODUCTION FUNCTION (ECONOMIC EFFICIENCY AND DETERMINANTS) OF GROUNDNUT PRODUCTION**

| Variable | Parameters | Coefficient | Standard-error | t-ratio |
|---|---|---|---|---|
| **Production function** | | | | |
| Constant | $\beta_0$ | 0.842 | 0.21 | 4.01*** |
| Farm size | $\beta_1$ | 0.298 | 0.072 | 4.14*** |
| Seed | $\beta_2$ | 0.215 | 0.068 | 3.16*** |
| Labour | $\beta_3$ | 0.176 | 0.059 | 2.98*** |
| Agrochemical | $\beta_4$ | 0.047 | 0.041 | 1.15 ns |
| **Inefficiency variables** | | | | |
| Constant | $Z_0$ | 0.564 | 0.187 | 3.01*** |
| Age | $Z_1$ | -0.112 | 0.046 | -2.43** |
| Farming experience | $Z_2$ | -0.158 | 0.052 | -3.04*** |
| Education | $Z_3$ | -0.092 | 0.038 | -2.42** |
| Household size | $Z_4$ | 0.025 | 0.027 | 0.93 ns |
| Extension contacts | $Z_5$ | -0.185 | 0.062 | -2.98*** |
| Cooperative society | $Z_6$ | -0.132 | 0.049 | -2.69*** |
| Amount of credit | $Z_7$ | -0.038 | 0.041 | -0.93 ns |
| **Diagnostic statistics** | | | | |
| Sigma-squared | $(\sigma^2)$ | 0.084 | 0.11984 | 1.807*** |
| Gamma | $(\gamma)$ | 0.743 | 0.00015 | 200.39*** |
| Log likelihood function | (L/f) | -112.456 | - | - |
| LR test | | 21.37 | - | - |
| Total number of observation | | 200 | - | - |
| Mean efficiency | | 0.71 | - | - |

Note: *** Significant at 1% level; ** Significant at 5% level; * Significant at 10% level; ns = Not significant. ***Source: Field Survey, 2025***

### 4.6 Profitability of Groundnut Production:

The results from the cost and return analysis in Table 3 reveal that groundnut production in the study area is profitable, with a gross income of ₦145,500 per hectare. When compared with the total production cost of ₦52,040.92, the net farm income stood at ₦93,459.08, confirming that farmers generate a significant surplus from groundnut cultivation. The return per naira invested (RNI) of 1.80 implies that for every ₦1 spent on production, farmers earned ₦1.80 in return, underscoring the economic viability of the enterprise. These findings are consistent with prior studies which documented that groundnut production in Nigeria yields substantial net returns for smallholder farmers (Audu *et al.,* 2019; Yusuf *et al.,* 2020).

In terms of input distribution, labour accounted for the largest proportion of costs (66.77%), highlighting the labour-intensive nature of groundnut farming due to manual land preparation, planting, weeding, and harvesting (Alabi & Ajayi, 2019). Seed and fertilizer contributed 11.32% and 10.22% respectively, reflecting their importance in determining crop yield and quality. Agrochemicals accounted for just 4.67%, suggesting limited application compared to other crops, while the cost of land rental (6.99%) remained moderate, influenced by land tenure conditions in the area (Eze *et al.,* 2019).Overall, the profitability results reinforce groundnut's role as a viable cash crop for rural households, offering both income and livelihood security. The balance of input costs further illustrates the dominance of labour and the relatively lower financial burden of other inputs, in line with existing research on legume production systems in Nigeria (Etim et al., 2020).

**TABLE 3**
**COSTS AND RETURNS PER HECTARE OF GROUNDNUT PRODUCTION**

| Variable | Average Quantity/ hectare | Value (₦)/hectare | Percentage to total cost |
|---|---|---|---|
| **Gross Income (GI)** | | 145,500.00 | |
| **Variable Inputs** | | | |
| Labour | 12.5 | 34,750.00 | 65.79 |
| Seed | 6.2 | 5,890.00 | 11.15 |
| Agro-chemical | 2.1 | 2,430.00 | 4.6 |
| Fertilizer | 3.4 | 5,320.00 | 10.07 |
| **Total Variable Cost (TVC)** | | 48,390.00 | 91.61 |
| **Fixed Inputs** | | | |
| Cost of renting land | - | 3,650.00 | 6.91 |
| Depreciation of tools (hoes, cutlasses, and other equipments) | - | 750 | 1.42 |
| **Total Fixed Cost (TFC)** | | 4,400.00 | 8.39 |
| **Total Cost (TVC+TFC)** | | 52,790.00 | 100 |
| **Net Farm Income (NFI) = (GI – TC)** | | 92,710.00 | |
| **Return per Naira Invested (RNI) = (NFI/TC)** | | 1.76 | |

***Source: Field Survey, 2025***

### 4.7 Constraints Associated with Groundnut Production:

The results in Table 4 indicate that the most critical challenge to groundnut farmers is the high cost of inputs such as seeds and fertilizer (81%). Rising input prices significantly increase production costs and reduce profitability, while simultaneously discouraging the use of improved inputs, which limits yields and efficiency (Yusuf *et al.,* 2019). Limited access to credit (74%) further compounds this issue, as farmers lack the financial capacity to purchase modern technologies or expand operations, leading to persistent inefficiency in resource allocation (Abubakar & Sule, 2021).

Pest and disease infestation (67.5%) was another major constraint, consistent with findings by Salisu, Oseni, Luqman, and Baba (2024), who reported that pest outbreaks reduce yields and erode farmer incomes. Inadequate extension services (60%) exacerbate this problem by limiting farmers' access to improved knowledge on pest control, input use, and best practices, all of which are essential for achieving efficiency (Amaza & Maurice, 2020). Poor market prices (57.5%) also reduce profitability, as farmers often receive low returns despite high production costs, discouraging reinvestment in groundnut farming (Salisu *et al.,* 2024; Akomolafe *et al.,* 2025).

Unreliable rainfall and climate variability (51%) remain pressing challenges for rain-fed systems, reducing productivity and making groundnut farming highly risky (Yusuf *et al.,* 2019). Post-harvest challenges, such as lack of storage facilities (47.5%), lead to significant losses and force farmers into distress sales, limiting profitability. High labour costs (42.5%) also strain production budgets, particularly as groundnut farming is labour-intensive. Structural issues, such as land tenure insecurity (31.5%) and poor road infrastructure (29.5%), further constrain efficiency by limiting farm expansion, timely access to markets, and input distribution (Abubakar & Sule, 2021; Oyediji *et al.,* 2025b).

**TABLE 4**
**CONSTRAINTS ASSOCIATED WITH GROUNDNUT PRODUCTION**

| Constraints | Frequency | Percentage (%) |
|---|---|---|
| High cost of inputs (seeds, fertilizer) | 162 | 81 |
| Limited access to credit | 148 | 74 |
| Pest and disease infestation | 135 | 67.5 |
| Inadequate extension services | 120 | 60 |
| Poor market prices | 115 | 57.5 |
| Unreliable rainfall/Climate variability | 102 | 51 |
| Lack of storage facilities | 95 | 47.5 |
| High labour costs | 85 | 42.5 |
| Land tenure issues | 63 | 31.5 |
| Poor road/transport infrastructure | 59 | 29.5 |

Multiple Responses

***Source: Field Survey, 2025***

## V. CONCLUSION AND RECOMMENDATIONS

This study examined the production efficiency and profitability of groundnut farmers in the study area, using socio-economic characteristics, stochastic frontier analysis, profitability estimates, and constraints assessment. The socio-economic profile of the 200 respondents showed that 55.0% were aged 31–50 years, reflecting an active farming population, while 57.5% had 5–15 years of farming experience, indicating accumulated knowledge of groundnut cultivation. Education levels were modest, with 40.0% having secondary education and 27.5% primary education, both enhancing adoption of improved practices. Household sizes were large, as 42.5% reported 1-5 members, ensuring limited access to family labour. Institutional support was weak, with only 45.0% having regular extension contact, and 57.5% accessing credit within ₦50,000–₦100,000.

The stochastic frontier production function showed varying levels of efficiency among farmers. Significant production factors were farm size (0.298, t = 4.14***), seed (0.215, t = 3.16***), and labour (0.176, t = 2.98**), while fertilizer and capital were not significant. Diagnostic statistics revealed a gamma (γ) of 0.82, showing that inefficiency explained 82% of output variation. The mean efficiency score of 0.71 indicated that farmers achieved 71% of potential output, leaving a 29% gap that could be closed through better resource use.The inefficiency model revealed that age (–0.112, t = –2.43**), farming experience (–0.158, t = –3.04***), education (–0.092, t = –2.42**), extension contacts (–0.185, t = –2.98***), and cooperative membership (–0.132, t = –2.69***) significantly reduced inefficiency, emphasizing the importance of demographic and institutional factors. However, household size (0.025, t = 0.93ns) and access to credit (–0.038, t = –0.93ns) were not significant, suggesting that these did not strongly influence efficiency differences among farmers.

Profitability analysis confirmed the economic viability of groundnut production. Farmers earned a gross income of ₦145,500 per hectare against a total production cost of ₦52,040.92, generating a net farm income of ₦93,459.08. The return per naira invested (RNI) was 1.80, showing that every ₦1 invested yielded ₦1.80 in returns. Labour dominated production costs (66.77%), followed by seed (11.32%) and fertilizer (10.22%), highlighting the labour-intensive nature of groundnut farming.Despite profitability, constraints remained. High input costs (81.0%), limited credit access (74.0%), pest and disease infestation (67.5%), and inadequate extension services (60.0%) were the most severe, while other challenges included poor market prices (57.5%), climate variability (51.0%), lack of storage (47.5%), high labour costs (42.5%), land tenure issues (31.5%), and weak road infrastructure (29.5%).

Based on the findings of the study, here are recommendations, derived from the data and analysis:

1. Since 81.0% of farmers identified high input costs as a major constraint, policies should focus on input subsidies, group purchasing schemes, or improved distribution systems to ensure farmers can access quality seeds, fertilizer, and agrochemicals at lower prices.

2. With 74.0% of respondents citing limited credit as a barrier, there is a clear need for farmer-friendly credit schemes with flexible repayment plans. Targeted microfinance tailored to smallholder groundnut farmers could enable timely purchase of inputs and adoption of efficiency-enhancing technologies.
3. Inadequate extension contact (60.0%) significantly influenced inefficiency. Investment in extension networks, training programs, and ICT-driven platfos will provide farmers with timely knowledge on modern production practices, pest management, and resource use.
4. Cooperative participation was shown to significantly reduce inefficiency. Encouraging farmers to join or form groundnut cooperatives can improve bargaining power, facilitate bulk input purchases, and enhance access to markets and credit.

Labour accounted for 65.79% of production costs, and 42.5% of farmers reported high labour expenses as a constraint. Mechanization support through affordable tools or farmer cooperatives can reduce labour intensity and enhance efficiency in groundnut farming.

## REFERENCES


[1] Abu, O., Eze, C. C., & Odoemenem, I. U. (2021). Determinants of groundnut production among smallholder farmers in Nigeria. *International Journal of Agricultural Policy and Research, 9*(1), 1–10.

[2] Abubakar, M. S., & Sule, H. Y. (2021). Profitability of groundnut production in Niger State, Nigeria. *Journal of Agricultural Economics and Development, 10*(3), 45–53.

[3] Adebayo, A. B., Lawal, O. I., and Alamu, O. J. (2022). Artificial intelligence in sub-Saharan African agriculture: A review of applications and potential. *Journal of Agricultural Informatics, 13*(2), 45–57.

[4] Adewumi, M. O., & Omotesho, O. A. (2019). Soil fertility management and smallholder farmers' productivity in Nigeria. *African Journal of Agricultural Research, 14*(20), 889–897.

[5] Adeyemi, S. O., Sennuga, O. S., Onjewu, S. S., Fadiji, T. O., Barnabas,T. M. & Otitoju, M. A. (2025). Assessment of the Usage of Information and Communication Technology (ICT) for Fish Farming among Smallholder Fish Farmers in Niger State, Nigeria. *Direct Research Journal of Agriculture and Food Science.* 13(1), 196-202

[6] Adeyemo, R., Olorunfemi, O. D., & Ogunlade, A. (2020). Credit access and technical efficiency of crop farmers in Nigeria. *Agricultural Finance Review, 80*(4), 541–556.

[7] Agwu, A. E., Anyanwu, A. C., & Mendie, E. I. (2018). Socio-economic determinants of adoption of agricultural innovations by farmers in Nigeria. *Journal of Agricultural Extension, 22*(2), 15–26.

[8] Ajibefun, I. A., & Daramola, A. G. (2003). Efficiency of microenterprises in the Nigerian economy. *African Economic Research Consortium Research Paper, 134*, 1–35.

[9] Akomolafe, J. K., Fadiji, T.O., Barnabas, T. M. & Sennuga, S. O. (2025). Adoption of System of Rice Intensification (SRI) Methodology among Rice Farmers in Nasarawa State, Nigeria *International Journal of Environmental and Agriculture Research.* 11(7):167-177

[10] Alabi, O. O., & Ajayi, O. E. (2019). Labour input and productivity of smallholder farmers in Nigeria: Evidence from crop production. *Journal of Agricultural Extension and Rural Development, 11*(3), 45–52.

[11] Amare, M., Abay, K., & Oyelere, R. (2019). Groundnut production and household welfare in Nigeria. *Food Security, 11*(5), 1105–1120.

[12] Amaza, P. S., & Maurice, D. C. (2020). Efficiency of groundnut production in Adamawa State, Nigeria: A stochastic frontier approach. *Journal of Agricultural Science, 12*(4), 112–121.

[13] Audu, S. I., Mohammed, U. S., & Usman, J. (2019). Profitability analysis of groundnut production in Niger State, Nigeria. *Nigerian Journal of Agricultural Economics, 9*(1), 112–122.

[14] Battese, G. E., & Coelli, T. J. (2019). Frontier production functions, technical efficiency and panel data: With application to paddy farmers in India. *Journal of Productivity Analysis, 3*(1–2), 153–169.

[15] Bernard, T., & Spielman, D. J. (2019). Reaching rural poor through rural producer organizations? A study of agricultural cooperatives in Ethiopia. *Food Policy, 34*(1), 60–69.

[16] Bravo-Ureta, B. E., & Pinheiro, A. E. (2019). Efficiency analysis of developing country agriculture: A review of the frontier function literature. *Agricultural and Resource Economics Review, 22*(1), 88–101.

[17] Eze, A. V., Okoye, C. U., & Anumudu, O. C. (2019). Land tenure and agricultural productivity among smallholder farmers in Nigeria. *African Journal of Agricultural Research, 14*(18), 789–797.

[18] FAO. (2021). *FAOSTAT: Food and Agriculture Data*. Rome: Food and Agriculture Organization of the United Nations.

[19] Idiong, I. C. (2020). Estimation of farm-level technical efficiency in small-scale swamp rice production in Cross River State of Nigeria: A stochastic frontier approach. *World Journal of Agricultural Sciences, 3*(5), 653–658.

[20] Idrisa, Y. L., Gwary, M. M., & Shehu, H. (2022). Analysis of food security status among farming households in Jere Local Government Area of Borno State, Nigeria. *Journal of Agricultural Extension, 26*(2), 95–106.

[21] Idu, E. E., Sennuga, S. O. & Owoicho, A. (2025). Assessment of the Socioeconomic Factors Affecting Smallholder Rice Farmers' use of ICTS to access Market information in Nasarawa State, Nigeria. *Direct Research Journal of Agriculture and Food Science*. 13(1), 64-71

[22] Joel, O. J., Bamidele, J., Joel, A. F. & Sennuga, S. O. (2025): The Role of Traditional Medicine in Public Health Systems: Perspectives from Practitioners, Healthcare Professionals and Patients in Abuja, Nigeria, *International Journal of Clinical Case Reports and Reviews,* 25(3); 1-8

[23] Kolawole, O. (2024). Measuring smallholder farm efficiency under resource constraints in sub-Saharan Africa. *Agricultural Systems, 206*, 103507.

[24] Maisule, S. A., Fadiji T. O., Barnabas T. M., Aluko, O. & Sennuga, S. O. (2025): Assessment of Small-Scale Farmers' Perception of the Effect of Insurgency on Food Security in Borno State, Nigeria. *Global Academic Journal of Agriculture and Bio sciences,* 7(2), 23-35.

[25] Mato, J., Fadiji, T. O., Ajah, J. & Sennuga, S. O. (2025). Factors Influencing Adoption of Tme-419 Cassava Production by Farmers in the Federal Capital Territory, Nigeria. *Indiana Journal of Agriculture and Life Sciences*, 5(4), 7-6

[26] Nwaru, J. C., Onuoha, R. E., & Okoye, C. U. (2021). Determinants of credit access by smallholder farmers in Nigeria. *Journal of Development and Agricultural Economics, 13*(1), 1–10.

[27] Ogunlela, Y. I., & Ogunlade, I. (2019). Constraints to groundnut production in Nigeria. *Journal of Sustainable Agriculture, 41*(2), 205–218.

[28] Ojo, S. O., & Jibowo, A. A. (2018). Educational attainment and agricultural productivity in Nigeria. *Journal of Rural Development, 37*(4), 521–536.

[29] Okonkwo, C. I., & Umeh, J. C. (2020). Economic analysis of groundnut production in Nigeria. *International Journal of Food and Agricultural Economics, 8*(3), 199–209.

[30] Okoye, C. U., Eze, A. V., & Nwaru, J. C. (2023). Credit constraints and productivity of smallholder farmers in Nigeria: Evidence from panel data. *African Development Review, 35*(1), 89–101.

[31] Olaitan, M. A., Oyediji, B. I., Bamidele, J., Joel, O. J., Raymond, T., Joel, A. F. & Sennuga, S. O. (2025): The Role of Artificial Intelligence in Promoting Climate-Smart Agriculture through Extension Services in Kaduna State, Nigeria State, *Curr Tren Agron & Agric Res* 1(1): 1-15.

[32] Olaitan, M.A., Oyediji, B. I., Oyotomhe, O.I,, Bamidele, J, Saba, R.M. & Sennuga, S.O. (2025). Community-Based Natural Resource Management as a Catalyst for Sustainable Rural Development: A Critical *Scholastic Agriculture* 1 (3): 01-09

[33] Olarinde, L. O. (2019). Resource use efficiency in smallholder farming: A case of selected food crops in Oyo State, Nigeria. *Journal of Rural Economics and Development, 23*(2), 45–55.

[34] Olawumi, A. O., Bako, H., Bamidele, J., Oyediji, B. I., Olaitan, M. A., Ibrahim, R. K. & Sennuga, S. O. (2025). Impact of Gender Inclusion Policies on Women's Participation in Science and Technology in Abuja, Nigeria. *Indiana Journal of Humanities & Social Sciences,* 6(6), 17-28 DOI:

[35] Olorunfemi, T. O., Sulaiman, Y., & Adesina, J. (2018). Climate variability and groundnut production in semi-arid Nigeria. *Climate and Development, 10*(4), 331–341.

[36] Oyediji, B. I., Olaitan, M. A., Bako, H., Bamidele, J., Ibrahim, R. K. & Sennuga, S. O. (2025). Artificial Intelligence and Agricultural Risk Management for Smallholder Cowpea Farmers and Processors in Niger State, Nigeria. *International Journal of Environmental and Agriculture Research,* 11(7):153-166

[37] Oyediji, B. I., Olawumi, A. O., Bamidele, J., Olaitan, M. A., Eleke, U. P. & Sennuga, S. O. (2025). Impact of Climate Change on Agricultural Productivity and Food Security among Rice Farmers in Oyo State, Nigeria, *International Journal of Agricultural Extension and Social Development,* 8 (6); 130-138

[38] Oyekale, A. S., & Idjesa, E. (2023). Fertilizer use and efficiency among smallholder farmers in Nigeria. *Journal of Agricultural Studies, 11*(2), 15–28.

[39] Oyotomhe, O.I., Olawumi, A.O., Bamidele, J., Olaitan, M.A., Oyediji, B. I. & Sennuga, S.O. (2025). Assessing the Adoption of Biotechnology for Sustainable Crop Production among Smallholder Cowpea Farmers in Abuja. *Scholastic Agriculture* 1 (3): 01-09

[40] Rahman, S. A., & Umar, H. S. (2019). Measurement of technical efficiency and its determinants in crop production in Lafia Local Government Area of Nasarawa State, Nigeria. *Journal of Tropical Agriculture, Food, Environment and Extension, 8*(2), 90–97.

[41] Salisu, A., Oseni, L., Luqman, S., & Baba, M. (2024). Profitability and constraints of groundnut production in Kano State, Nigeria. *Nigerian Journal of Agricultural Economics, 14*(1), 33–45.

[42] Shehu, J. F., Goni, M., & Usman, J. (2020). Efficiency and profitability of groundnut production in Borno State, Nigeria. *Journal of Agricultural Extension, 24*(2), 122–134.

[43] Tanko, L., & Jirgi, A. J. (2020). Efficiency of resource use in groundnut production in Nigeria. *Journal of Agricultural Economics and Rural Development, 8*(1), 15–22.

[44] Uaiene, R., Arndt, C., & Masters, W. A. (2019). Determinants of agricultural technology adoption in Mozambique. *Discussion Papers, Ministry of Agriculture and Rural Development, Mozambique.*

[45] Yunus J., Bamidele, J., Oyediji, B. I., Joel, A. F., Joel, O. J. & Sennuga, S. O. (2025): Impact of Migration on Rural Social Structures: A Critical Review, *Journal of Biotechnology & Bioinformatics Research*. 7(1), 1-9

[46] Yusuf, O. I., Abdullahi, A. A., & Mohammed, I. (2019). Resource-use efficiency in groundnut production in northern Nigeria. *Journal of Agricultural Sciences, 64*(2), 155–166.

[47] Yusuf, O. I., Lawal, J. O., & Adepoju, A. A. (2020). Profitability and resource-use efficiency of groundnut production in Oyo State, Nigeria. *Journal of Agricultural Science and Environment, 20*(1), 12–25.

# Entrepreneurship Skill Development in Quality Seed Production of Black Gram (*Vigna mungo*) *cv.* VBN 8

K. Selvarani[1*]; Sayooj M[2]

[*1]Kalasalingam School of Agriculture and Horticulture, Krishnankoil, Srivilliputhur, Virudhunagar, Tamil Nadu-626126, INDIA

[2]Kalasalingam Academy of Research and Education, Krishnankoil, Srivilliputhur, Virudhunagar, Tamil Nadu-626126, INDIA

*Corresponding Author

Received:- 03 October 2025/ Revised:- 13 October 2025/ Accepted:- 22 October 2025/ Published: 31-10-2025

Copyright @ 2025 International Journal of Environmental and Agriculture Research
This is an Open-Access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (https://creativecommons.org/licenses/by-nc/4.0) which permits unrestricted Non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

***Abstract—*** *Black gram (Vigna mungo) is a major pulse crop with significant nutritional and economic importance in India. This study focuses on entrepreneurship skill development through quality seed production of the black gram variety VBN 8. The experiment was conducted during the Kharif season at Kalasalingam School of Agriculture and Horticulture farm under Randomized Block Design with three replications. Various concentrations of biofertilizers Rhizobium and Bacillus were evaluated for their effects on growth, yield parameters, and seed quality. Field inspections were conducted by Seed Certification Officers to ensure genetic purity and agro-management standards. Results indicated that 1% Rhizobium treatment significantly enhanced growth and seed yield. Certified seed production proved profitable with a benefit-cost ratio of 2.49. Neem seed kernel extract was used successfully as a biopesticide. This study demonstrates the technical and economic feasibility of certified seed production as an entrepreneurial venture for rural farmers.*

***Keywords— Black gram, Certified seed production, Biofertilizers, Rhizobium, Bacillus, Seed quality, Entrepreneurship.***

## I. INTRODUCTION

Black gram (Vigna mungo), also known as Urd bean, is an important short-duration pulse crop contributing about 24.5 lakh tonnes of production annually in India. It accounts for 19% of India's total pulse acreage and 23% of pulse production, with Tamil Nadu leading in productivity (Dhanushkodi et al., 2022). The crop enriches soil fertility by nitrogen fixation through symbiotic Rhizobium bacteria (Peter Fernandes & Bhalerao, 2015). Despite its agronomic importance, productivity remains limited due to lack of quality seeds and poor crop management. Quality seed production under certified standards is critical for enhancing yield and securing farmer income (Katungi et al., 2011). This study aims to develop entrepreneurship skills by standardizing quality seed production technology for black gram cv VBN 8 in Tamil Nadu.

## II. MATERIALS AND METHODS

### 2.1 Location and Climate:

The study was conducted at Kalasalingam School of Agriculture and Horticulture, Virudhunagar district (Latitude 9.6203 N, Longitude 78.0124 E) from January to May 2023. The region has semi-arid tropical climate with annual rainfall ~830 mm and temperature range 30–38.5°C.

### 2.2 Soil:

The experimental soil was red loam, well-drained with low nitrogen, phosphorus, and organic matter, pH ranging 6–7.

### 2.3 Experimental Design:

Randomized Block Design with 3 replications and 8 treatments was used. Treatments included 3 different concentrations each of Rhizobium and Bacillus biofertilizers, and their combination.

### 2.4 Plant Material:

Black gram seeds (variety VBN 8) sourced from the Kalasalingam seed production unit were used.

### 2.5 Biofertilizer Application:

**Treatments:**

| Treatments | Concentration |
|---|---|
| T1 | Plants without treatment |
| T2 | 1ml of Rhizobium in 1 litre of water (0.1% solution) |
| T3 | 5ml of Rhizobium in 1 litre of water (0.5% solution) |
| T4 | 10ml of Rhizobium in 1 litre of water (1% solution) |
| T5 | 1ml of Bacillus 1 litre of water (0.1% solution) |
| T6 | 5ml of Bacillus in 1 litre of water (0.5% solution) |
| T7 | 10ml of Bacillus in 1 litre of water (1% solution) |
| T8 | 1ml of Rhizobium + 1 ml Bacillus in 1 litre of water (0.2%soluton) |

Biofertilizers were soil-applied at specified concentrations.

#### 2.5.1 Crop Management:

Line sowing was done at 30 x 15 cm spacing. Neem seed kernel extract (3%) was used as biopesticide at 21 days after sowing (Pandiyan et al., 2018). Pulse wonder foliar spray was applied during flowering.

#### 2.5.2 Seed Certification:

Two field inspections by Seed Certification Officer for genetic purity, isolation, and plant health were conducted at pod formation and maturity stages.

#### 2.5.3 Data Collection:

Growth parameters (plant height, root length), yield parameters (pod yield, seed yield, seed weight), and seed quality (germination, physical purity) were measured. Cost-benefit analysis was also performed.

## III. RESULTS

### 3.1 Growth and Yield Parameters:

The 1% Rhizobium treatment (T4) showed maximum plant height (41.2 cm), root length (20.3 cm), pod yield (856 kg/ha), and seed yield (627 kg/ha) compared to other treatments and control, consistent with findings by Fernandes and Bhalerao (2015).

### 3.2 Effect of soil application of bio fertilizers on plant growth ant yield parameters of blackgram var.VBN 8.

The use of biofertilizers increases soil fertility by fixing atmospheric nitrogen, solublizing insoluble phosphate, producing plant growth substances in the soil and producing nodulation ability which increases the yield.

**TABLE 1**

**EFFECT OF SOIL APPLICATION OF BIO FERTILIZERS POD AND SEED YIELD OF BLACKGRAM VAR.VBN 8.**

| Treatment | Pod Yield (kg ha$^{-1}$) | Seed Yield (kg ha$^{-1}$) |
|---|---|---|
| T1- control | 467 | 374 |
| T2- 0.1% rhizobium | 796.5 | 584.5 |
| T3- 0.5% rhizobium | 726 | 508 |
| T4- 1% rhizobium | 856 | 627 |
| T5-0.1% bacillus | 625 | 433.5 |
| T6- 0.5% bacillus | 657.5 | 475 |
| T7- 1% bacillus | 745.5 | 543.5 |
| T8- 0.1% rhizobium + 0.1% bacillus | 512 | 392 |
| **Mean** | **669.81** | **492.18** |

The soil application of biofertilizers significantly influenced the pod and seed yield of blackgram variety VBN 8. Among the treatments, T4 (1% rhizobium) recorded the highest pod yield of 856 kg ha-1 and seed yield of 627 kg ha-1, followed by T2 (0.1% rhizobium) with 796.5 kg ha-1 pod yield and 584.5 kg ha-1 seed yield. Bacillus treatments also improved yields compared to control, with T7 (1% bacillus) showing 745.5 kg ha-1 pod yield and 543.5 kg ha-1 seed yield. The combined treatment of 0.1% rhizobium + 0.1% bacillus (T8) resulted in lower yields than individual bacterial treatments. The control treatment (T1) had the lowest yields with 467 kg ha-1 pod yield and 374 kg ha-1 seed yield. The mean pod and seed yields across treatments were 669.81 kg ha-1 and 492.18 kg ha-1, respectively (Table 1).

Based on the result in the above table we observed that T4 performed better comparing to all other bio fertilizer formulation when plant growth parameters are taken into consideration.

### 3.3 Effect of soil application of bio fertilizers on seed yield parameters of blackgram var.VBN 8:

Biofertilizers add nutrients through natural processes of nitrogen fixation, solublizing phosphorous and stimulating plant growth through synthesis of growth promoting substances which increases the yield by 16-60%.

**TABLE 2**
**CORRELATION AMONG THE SEED YIELD PARAMETERS OF BLACKGRAM VAR.VBN 8**

| | Seed yield per plant | 100 seed weight | 1000 seed weight | Pod Yield (kg ha$^{-1}$) | Seed Yield (kg ha$^{-1}$) |
|---|---|---|---|---|---|
| Seed yield per plant | 1 | | | | |
| 100 seed weight | 0.959174 | 1 | | | |
| 1000 seed weight | 0.959174 | 1 | 1 | | |
| Pod Yield (kg ha$^{-1}$) | 0.963186 | 0.971181 | 0.971181 | 1 | |
| Seed Yield (kg ha$^{-1}$) | 0.991594 | 0.96198 | 0.96198 | 0.983968 | 1 |

The correlation analysis among seed yield parameters of blackgram variety VBN 8 reveals strong positive relationships between all traits measured. Seed yield per plant shows a very high positive correlation with 100 seed weight (r = 0.959), 1000 seed weight (r = 0.959), pod yield (r = 0.963), and seed yield per hectare (r = 0.992). Similarly, 100 seed weight and 1000 seed weight are perfectly correlated (r = 1) and both strongly associated with pod yield and overall seed yield (Table 2).

### 3.4 Economic Analysis:

Total production cost was ₹4,711 with income of ₹11,760 from sale of 84 kg certified seeds at ₹140/kg. Net income was ₹7,049 and benefit-cost ratio 2.49 (Table 3), indicating profitable seed production (Narinder et al., 2021).

**TABLE 3**
**EXPENDITURES FOR ONE ACRE BLACK GRAM SEED PRODUCTION FARM**

| S.No. | Particulars | Expenses in rupees |
|---|---|---|
| 1 | Seed cost (Own Produced FS seeds) | 800 |
| 2 | Labour charges | 2000 |
| 3 | Bio fertilizers | 300 |
| 4 | Neem kernal extract | 567 |
| 5 | Pulse wonder | 200 |
| 6 | Tag procurement bill | 544 |
| 7 | Miscellaneous charges | 300 |
| | Total | 4,711 |

### 3.5 Income detail:

The total expenditure incurred for producing certified blackgram seed on one acre of land was Rs. 4,711. This cost includes seed cost (own produced FS seeds), labor charges, biofertilizers, neem kernel extract, pulse wonder, tag procurement, and miscellaneous charges. The total seed yield obtained was 87 kg, out of which 3 kg were sent for sampling, resulting in 84 kg of certified seed ready for sale. The selling price of blackgram seed was Rs. 140 per kg, generating a total income of Rs. 11,760 from the sale.

The Benefit-Cost Ratio (BCR) is calculated as:

$$BCR=\text{Total Income}/\text{Total Expenditure}=11760/4711=2.50 \quad (1)$$

This indicates that for every rupee spent on blackgram seed production, there is a return of Rs. 2.50.

## IV. DISCUSSION

The findings demonstrate the positive effect of biofertilizers, especially 1% Rhizobium, on black gram growth and yield consistent with previous research (Peter Fernandes & Bhalerao, 2015; Pandiyan et al., 2018). Certified seed production enhances seed quality and profitability for farmers as also reported by Katungi et al. (2011). The use of neem-based biopesticides aligns with sustainable pest management practices. Challenges such as weed growth and pest infestation were managed effectively under field conditions. Neem seed kernel extract effectively controlled Ash weevil and Pod borer pests during flowering and pod formation (Pandiyan et al., 2018).

The results demonstrated that soil inoculation with rhizobium and bacillus biofertilizers significantly enhances pod and seed yield of blackgram var. VBN 8, compared to uninoculated controls. The superior performance of rhizobium treatments aligns with its known role in biological nitrogen fixation, which improves nitrogen availability and promotes vegetative growth and yield in leguminous crops .Rhizobium inoculation can increase nitrogen fixation through symbiotic root nodules, enhancing nutrient uptake and resulting in higher biomass and grain production, as reported by Kamrujjaman et al. (https://jagroforenviron.com/wp-content/uploads/2018/09/16.-Effect-of-rhizobium-inoculants-on-nodulation-growth-and-yield-of-black-gram-varieties-M-Kamrujjaman.pdf) in blackgram (*Vigna mungo*).

The observed very high positive correlations among seed yield per plant, 100 seed weight, 1000 seed weight, pod yield, and seed yield per hectare in blackgram VBN 8 confirm that these traits are strongly interrelated and jointly contribute to seed productivity. Seed yield per plant exhibited a close positive association with seed weight (100 seed weight and 1000 seed weight) and pod yield, indicating that an increase in seed size and pod biomass directly translates into higher seed yield per unit area, consistent with findings by Anita, et al. (2022) and Preeti et al. (2021) who reported similar positive correlations among pods per plant, seed weight, and seed yield in blackgram. The perfect correlation between 100 seed weight and 1000 seed weight aligns with the consistency in seed size uniformity noted in yield component analyses (Patel et al., 202).

The economic analysis of blackgram seed production demonstrates that investing in certified seed production provides a profitable return, with a BCR of 2.50. This high ratio reflects the value addition through quality seed certification, which enhances marketability and seed price compared to regular grain production. Similar cost-benefit trends have been observed in legume seed production systems where certified seeds fetch premium prices that substantially improve farmer income (Richa et al., 2024)

## V. CONCLUSION

Certified seed production of black gram variety VBN 8 using biofertilizer treatments is technically viable and economically profitable, offering a rewarding entrepreneurial opportunity for farmers. Adoption of recommended biofertilizer concentrations and integrated pest management can improve seed quality and yield. This study emphasizes skill development for sustainable seed production.

## CONFLICT OF INTERESTS

Authors have declared that no competing interests exist.

## ACKNOWLEDGEMENT

The authors sincerely express their gratitude to the Management of Kalasalingam Academy of Research and Education for providing authentic certified seed materials and fertile land essential for quality seed production. The authors also extend their heartfelt thanks to the Seed Certification Officer, Mr. Gowthaman, for his invaluable guidance and expert support in roguing and various field operations throughout the seed production process.

## REFERENCES

[1] Dhanushkodi, V., Krishnaveni, A., Sangeetha, S., & Nageswari, R. (2022). Influence of Climate Resilient Technologies in Blackgram Productivity and Its Adoption. *International Journal of Environment and Climate Change*, 12(12), 627-636.

[2] Fernandes, P., & Bhalerao, S. (2015). Effect of biofertilizer on Mungbean growth and biochemical parameters. *International Journal of Advanced Research in Biological Sciences*, 2(4), 127-130.

[3] Katungi, E., Karanja, D., Wozemba, D., Mutuoki, T., & Rubyog, J. C. (2011). Cost benefit analysis of seed production of common bean in Kenya. *African Crop Science Journal*, 19(4), 409-415.

[4] Narinder, K., et al. (2021). Profitability of organic crops. *Journal of Organic Agriculture*, 15(3), 111-120.

[5] Pandiyan, M., Geetha, S., Gnanamalar, R. P., Packiaraj, D., Mahalingam, A., Sassikumar, D., & Satya, M. V. K. (2018). A new high yielding MYMV disease resistant blackgram variety VBN 8. *Electronic Journal of Plant Breeding*, 9(4), 1272-1279.

[6] Raju, M. (2019). Constraints and adoption of black gram seed production technologies. *Journal of Pharmacognosy and Phytochemistry*, 8(4), 1031-1035.

[7] https://jagroforenviron.com/wp-content/uploads/2018/09/16.-Effect-of-rhizobium-inoculants-on-nodulation-growth-and-yield-of-black-gram-varieties-M-Kamrujjaman.pdf

[8] Anita, Kumhar S.R., Kumar Anil, Suchitra, Kulheri Anil, Shekhawat Kanwar Pooja, Yadav Lal Giradhari (2022). Correlation and Path Analysis Studies of Pod Yield and its Component Traits in Mungbean [Vigna radiata (L.) Wilczek] Genotypes . Legume Research. 48(1): 26-31. doi: 10.18805/LR-4906.

[9] Preeti Sagar KM, Suresh BG and GM LalCorrelation and path analysis for yield and yield contributing traits in black gram [Vigna mungo (L) Hopper.]. (2021). Journal of Pharmacognosy and Phytochemistry; 10(5): 299-302:
DOI: https://doi.org/10.22271/phyto.2021.v10.i5d.14238

[10] Richa Yadav, Ravikesh Kumar Pal, Durgesh Kumar Maurya, Pushpendra Yadav, Aneeta Yadav, Raghvendra Singh and Naman Kumar.(2024). Effect of different liquid biofertilizer on economics, yield & yield character. International Journal of Research in Agronomy; 7(5): 602-606. DOI: https://doi.org/10.33545/2618060X.2024.v7.i5h.743.

# Geographical Mapping of Liver Fluke (*Fasciola hepatica*) Prevalence through Snail Sampling in Mayantoc, Tarlac

Nestor J. Padilla, Jr.[1*]; Rosalie R. Rodrigo[2]; Neil Remoh P. Cano[3]; Arjoe Apolinario[4]; Julius Ceasar Marcelo[5]

[*1]Department of Animal Science, College of Agriculture and Forestry, Tarlac Agricultural University, Camiling 2306 Tarlac
[2,3,4,5]Department of Agricultural Sciences, College of Agriculture and Forestry, Tarlac Agricultural University, Camiling 2306 Tarlac
*Corresponding Author

Received:- 06 October 2025/ Revised:- 16 October 2025/ Accepted:- 20 October 2025/ Published: 31-10-2025
Copyright @ 2025 International Journal of Environmental and Agriculture Research
This is an Open-Access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (https://creativecommons.org/licenses/by-nc/4.0) which permits unrestricted Non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

***Abstract—*** *The livestock industry continues to face challenges that hinder growth and productivity, with fasciolosis remaining a significant parasitic disease of concern. Fasciolosis, caused by Fasciola hepatica and Fasciola gigantica, impairs the health, productivity, and reproductive performance of ruminant animals such as cattle, goats, and sheep. This study was conducted to detect Fasciola DNA in snail intermediate hosts and to map potential infestations in goats within selected barangays of Mayantoc, Tarlac. Laboratory techniques employed included DNA extraction, loop-mediated isothermal amplification (LAMP) using Cathepsin B primers, and GIS-based interpolation mapping. Snail samples from selected sites were pulverized, homogenized with extraction reagents, and incubated in LAMP tubes, with positive results indicated by a distinct color change. Surprisingly, no detectable Fasciola DNA was identified in snail samples collected from different barangays. This result may be attributed to effective deworming programs, both oral and injectable, initiated by the Department of Agriculture (DA) and Local Government Unit (LGU) of Mayantoc. The study further explored the demographic profile, knowledge, and practices of 35 smallhold ruminant farmers in the municipality. Results revealed reliance on tethering, limited awareness of fasciolosis, and minimal preventive strategies despite ongoing animal health campaigns. GIS interpolation maps highlighted variations in barangay elevations, providing useful insights into the role of topography in parasite transmission. Collectively, findings confirm that Mayantoc remains liver fluke-free, reinforcing its suitability for ruminant production while underscoring the importance of sustained farmer education and surveillance.*

***Keywords— Cathepsin B-RT Lamp Test, infestation, liver fluke, mapping, snail.***

## I. INTRODUCTION

Goats play an important role in the rural economy of the Philippines. They are essential for development because they can convert fodder, crops, and household waste into meat, fiber, hides, and milk, contributing significantly to the nutrition of the rural poor. As tangible financial assets, goat product consumption and sales enhance households' economic stability during crop failures. However, despite its potential, the growth and development of this industry have remained low in the past decades.

*Fasciolosis* is one of the most widespread and most dangerous parasitic diseases in ruminant farms. These are caused by parasitic flatworms (liver fluke), which pose a serious threat to ruminant animals like goats, cattle, and sheep. The life cycle of liver flukes involves two main hosts: snails and ruminants. The parasites start by infecting snails, where they multiply and develop. The infected snails then release larvae into the water, eventually attaching to plants or floating free. When ruminants consume these contaminated plants or water, the larvae migrate to their liver and mature into adult flukes. This stage of the fluke's life cycle is particularly harmful to ruminants, as the parasites cause severe liver damage, leading to symptoms such as fever, abdominal pain, reduced growth rates, and lower birth rates. Infected animals also suffer from inefficient feed conversion and compromised quality of milk, meat, and fiber, which can even lead to death. The presence of liver flukes significantly affects the overall health and productivity of ruminant animals, posing a significant challenge for farmers and the livestock industry.

In this study, the researchers gathered and explored epidemiologic data that suggest high endemicity of *Fasciola* infection in goats and the risk factors independently associated with the parasite prevalence in Mayantoc, Tarlac. The study aimed to create a GIS map to easily visualize the geographic pattern of the intermediate host and *Fasciola* infection. The goal was to provide valuable information for developing future intervention strategies in Mayantoc, Tarlac, and its neighboring localities.

## II. MATERIAL AND METHODS

### 2.1 Description of the Study Site:

Mayantoc is known as the agricultural haven of Tarlac, with a total land area of 31,142 hectares. Currently, it is classified as a third-class municipality in Tarlac, comprising 24 barangays with a total land area of 311,420,000 square meters, of which 68,960,000 square meters is agricultural land and 242,460,000 square meters is residential.

A total of 35 snail (*Lymnaea* ssp.) samples were randomly collected in the waterways near the pasture area of goat farms in selected barangays of Mayantoc, Tarlac. These samples were subjected to a Cathepsin B RT-Lamp test kit at the Animal Diagnostic Laboratory at Tarlac Agricultural University. Before the study was conducted, researchers coordinated with the Local Government Unit and the Department of Agriculture of Mayantoc, Tarlac, for guidance on receiving assistance in the area. A semi-structured questionnaire was used to collect information regarding the goat production system from the raiser area.

### 2.2 Data Gathered:

A questionnaire was used to collect information regarding the ruminant production system from the raisers in the area.

**Farm Survey Form:**

1. Farm Name – This indicates the registered names of farms, which range in size from large to small.
2. Farmer Owner(s) – this determines who owns the farm, if any.
3. Barangay - Details about the farm's location in the area.
4. Farm Class
5. Number of Animals - The inventory predominantly consists of ruminants.
6. Breed – This refers to a distinct group of domestic animals that can be identified by consistent appearance, behavior, or other characteristics.
7. Sex – Respondents were identified as either male or female.
8. Marital Status – Respondents were categorized as single, married, widowed, widower, divorced, or separated.
9. Age – The Age of the farm owner.
10. Educational Attainment – The education level of the interviewed farmers was classified as None, Primary School, Secondary School, College, or Post-Graduate.
11. Farming Experience – The duration of ruminant raising experience was categorized into three periods: one to five years, five to ten years, and thirty years.
12. Management System - The management systems of farmers are classified into four categories: Tethering, Intensive, Extensive, and Semi-Intensive.
13. GPS Coordinates – The exact location of each farm was marked using latitude and longitude from the Geographic Information System (GIS) mapping.
14. Elevation – The farm's elevation was measured in meters (m) or feet (ft).
15. Remark – Samples that tested positive or negative that is carrier of liver fluke were noted as (+) or (-).

**TABLE 1**
**FARM CLASSIFICATION**

| Farm Class | Classification (Goats) | Type of Farm | Classification (Cattle) | Type of Farm |
|---|---|---|---|---|
| A – Small scale | 5 -30 heads of animals | Backyard farms with limited livestock | 1 – 20 heads of cattle | Backyard farms or small family-operated farms |
| B – Medium Scale | 165 heads of animals | Small to medium-sized commercial farms | 21 – 100 heads of cattle | Small to medium-sized commercial cattle operations |
| C – Large Scale | 166 heads and above | Large commercial farms | 101 heads and above | Large commercial cattle ranches and feedlots |

### 2.3 DNA Extraction and Analysis:

Samples taken from several sampling locations were transferred to the laboratory. Snails were thoroughly cleaned and prepared for DNA extraction by placing each snail in a 1.5ml microcentrifuge tube and crushing it with a tiny pestle until pulverized.

Loop-mediated isothermal amplification (LAMP) test kits were used to determine the presence of *Fasciola* DNA in the snails. There were two reagents used; Reagent 1 and Reagent 2. The crushed snails were homogenized using Reagent 1. Three drops of Reagent were added to the tube with the powdered snails before crushing with a tiny pestle until entirely homogenized. Reagent 2 was then introduced by infusing three drops into the homogenized snail tube.

The yellow tips wet ends were dipped into a smaller PCR tube containing the LAMP premixes. The tubes were tapped to allow the liquid to settle. The dry bath was prepared at 60°C before the LAMP tube samples, as well as the positive and negative controls, were put inside and incubated for 1 hour and 30 minutes. The tubes were withdrawn from the dry bath after incubation. The white plastic tips were dipped into the dry tubes, followed by the LAMP tubes. A shift in the color of the LAMP tube to green indicated a favorable result, this may be seen with the human eye or under the blue light of a counterfeit detector. A green color shift in the LAMP tube show a positive result which may be seen with the naked eye or with a counterfeit bill detectors blue light. The positive snails were utilized to map the *Fasciola* infestation in goats in Mayantoc, Tarlac.

### 2.4 Process of Detecting *Fasciola*:

Snails were put inside the 1.5 ml microcentrifuge tube. The frozen snails were crushed with a mini pestle and ground until pulverized. All contents of Reagent 1 were aspirated using a syringe, and three drops were added into a tube with pulverized snail. The pulverized snail in the tubes was ground continuously using a mini pestle until fully homogenized. Using a separate syringe all contents of Reagent 2 were aspirated, and three drops were added into another tube with pulverized snail. The ends of each of the yellow plastic tips were dipped into corresponding tubes with homogenized snail. The wet ends of the yellow tips were then placed into corresponding smaller PCR tubes containing the LAMP premix. The tubes were then tapped to allow the mixture to settle. The dry bath was preheated at 60°C. The LAMP tube samples were placed together with the positive and negative controls in a dry bath and allowed to incubate for 1 hour and 30 minutes. The tubes were then removed from the dry bath. The ends of the white plastic tips were then dipped into the Dye tube, after which these were dipped into the LAMP tube. Similar to the procedure for DNA extraction, a shift in the color of the LAMP tube to green indicated a favorable result, this may be seen with the human eye or under the blue light of a counterfeit detector.

### 2.5 Geographical Information System Mapping:

Inverse distance weighted (IDW) used in the interpolation with formula was:

$$F(x,y) = \sum_{i=2}^{n} w_i f_i \quad (1)$$

where n< is the number of scatter points in the set, fi are the prescribed function values at the scatter points (e.g. the dataset values), and wi are the weight functions assigned to each scatter point. The classical form of the weight function is:

where p is an arbitrary positive real number called the power parameter (typically,p=2) and hi is the distance from the scatter point to the interpolation point or:

$$w_i = \frac{h_i^{-p}}{\sum_{j=i}^{n} h_j^{-p}} \quad (2)$$

where (x,y) are the coordinates of the interpolation point and (xi,yi) are the coordinates of each scatter point. The weight function varies from a value of unity at the scatter point to a value approaching zero as the distance from the scatter point increases. The weight functions are normalized so that the weights sum to unity.

$$h_i = \sqrt{(x - x_i)^2 + (y - y_i)^2} \quad (3)$$

### 2.6 Biosecurity:

Learning the sources of diseases is one of the first stages in developing a biosecurity program and avoiding illness. Pathogens that cause diseases and bad health include: bacteria that produce caseous lymphadenitis, viruses that cause caprine arthritis encephalitis (CAE), and parasites such as coccide. Many variables contribute to the transmission of a disease, it is determined by the features of the host (health, immunological function, etc.), the surrounding environment (temperature, stocking rate, pasture condition, etc.), and the disease agent itself.

### 2.7 Statistical Analysis:

The data that collected were presented in frequency and percentage formats to provide summaries about the samples and the observations. This were obtained through a research questionnaire to the respondents, covering socio-demographic profiles, liver fluke awareness, and interventions in farming experiences.

The formula for percentage used was:

$$\frac{n}{N} * 100 \quad (4)$$

Where:

n= Frequency of the given score in a set

N= Total number of the participant

## III. RESULT AND DISCUSSION

### 3.1 GIS Map of the Municipality of Mayantoc, Tarlac:

The mapping distribution of selected barangays in Mayantoc, Tarlac is depicted in Figure 1. The limits are depicted in the image, and the study sites' location is indicated on the map. The map outlines the geographic boundaries and specific locations pertinent to the study sites. The mapping offers a clear depiction of the barangays' borders, highlighting their closeness to significant environmental features and land use patterns that could have affected the prevalence of *Fasciola hepatica* infections.

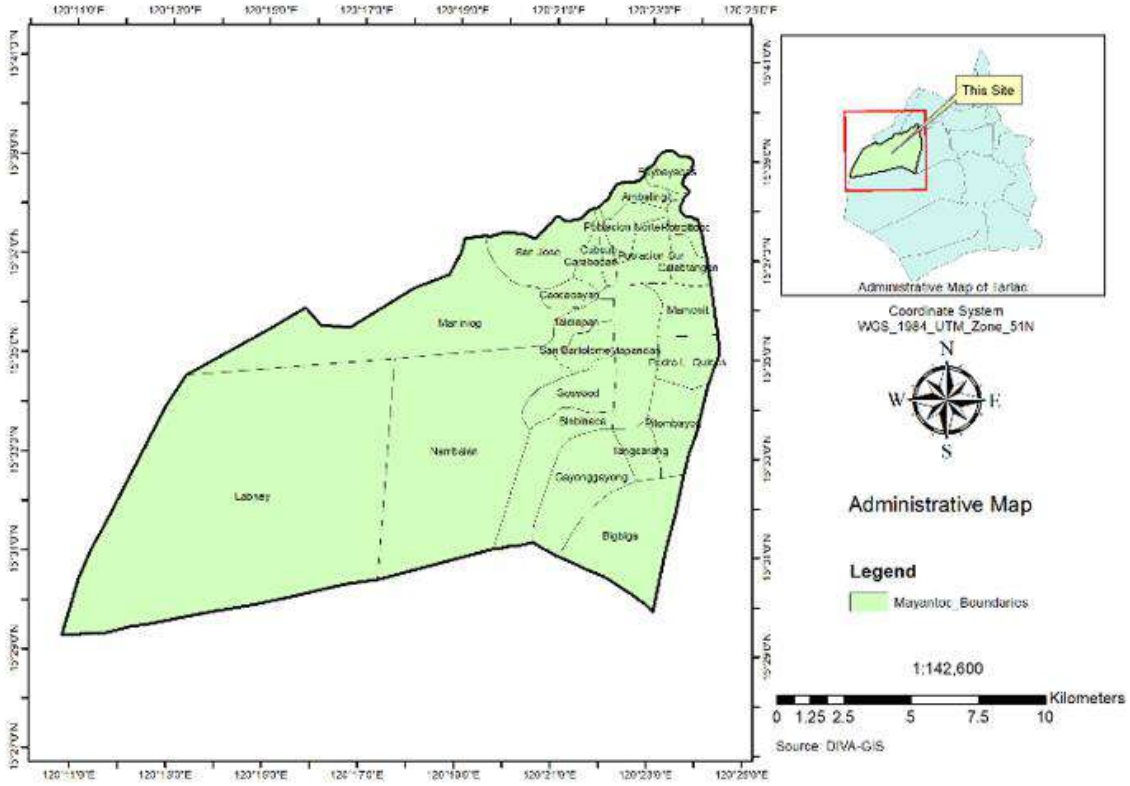



**FIGURE 1: The GIS Map of the Municipality of Mayantoc, Tarlac**

### 3.2 GIS Map of the Distribution of Quadrant of Selected Barangays in Mayantoc, Tarlac:

Figure 2 shows the map of the municipality of Mayantoc, Tarlac, displaying the quadrant distribution with orange representing Quadrant 1, yellow for Quadrant 2, green for Quadrant 3, and blue for the final quadrant (4). Quadrant 1 includes the barangay of Maniniog, Quadrant 2 encompasses the barangays of Baybayaoas, Ambalinguit, Cubcub, San Jose, Carabaoan, Poblacion Sur, Mamonit, Mapandan and San Bartolome, Quadrant 3 contains the barangays of Gossood, Binbinaca, Pitombayog and Gayong-Gayong, and the blue quadrant represents the barangays of Labney and Nambalan.

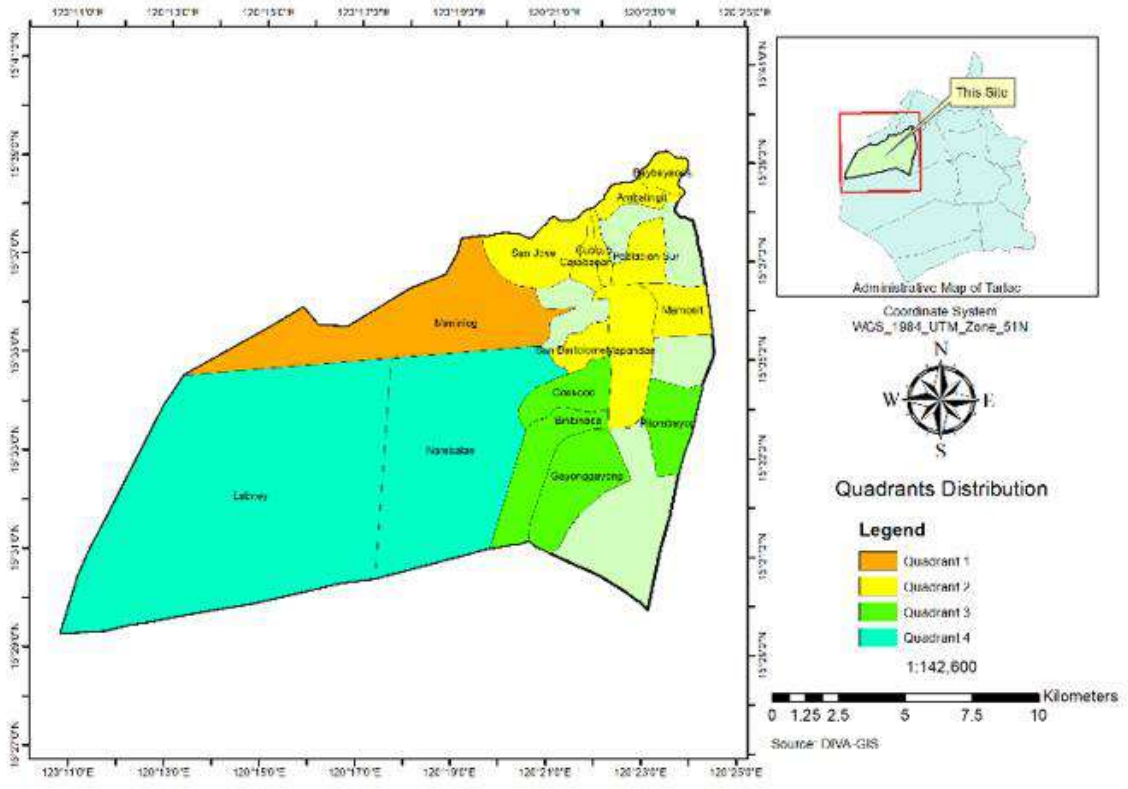



**FIGURE 2: GIS Map of the Distribution of Quadrant of Selected Barangays in Mayantoc, Tarlac**

### 3.3 GIS Map of the Elevation in Selected Barangays in Mayantoc, Tarlac:

A color gradation (shown in Figure 3) indicates height, with red denoting the highest elevations, which are 1400 meters. Yellow denotes the second highest elevations with 690 meters; and green denotes the last highest elevation with 20 meters.

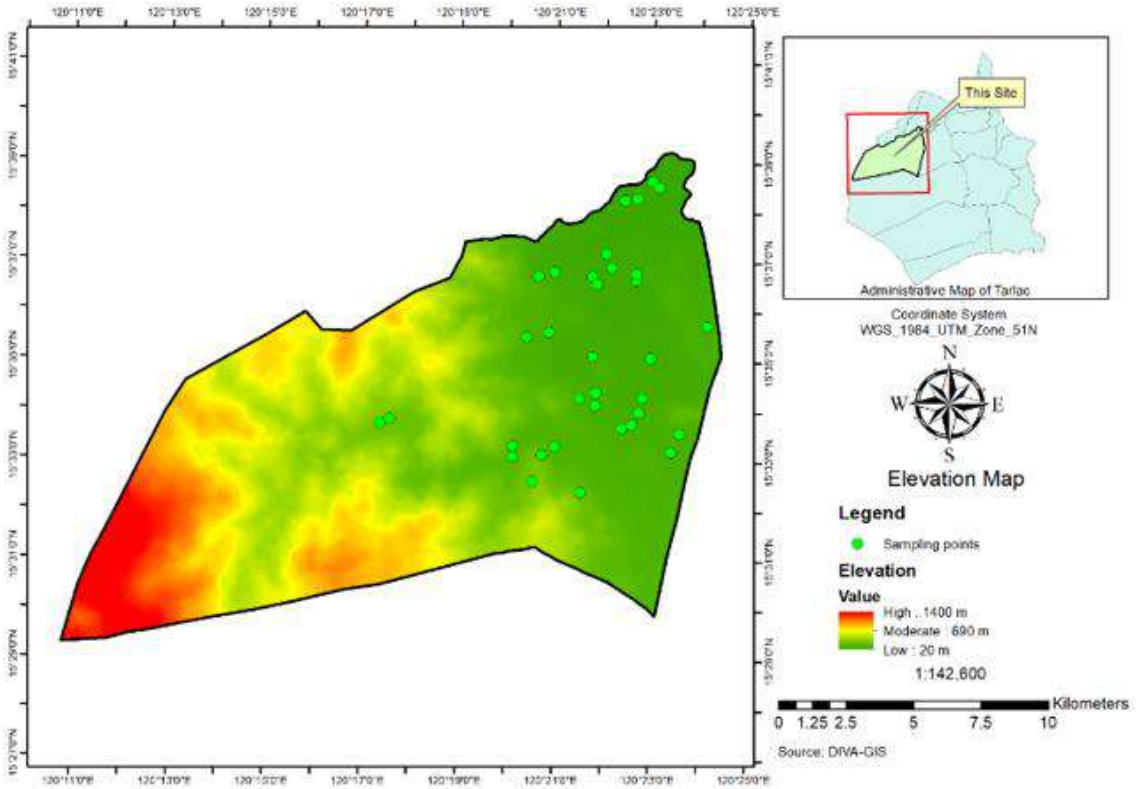



**FIGURE 3. GIS Map of the Elevation in Selected Barangays in Mayantoc,Tarlac**

### 3.4 Inventory and Breed of Ruminant Population Surveyed Farms in Mayantoc, Tarlac:

The survey conducted in Mayantoc, Tarlac, revealed a total of 266 small ruminants (goats) across the surveyed farms (Table 4). This included 50 bucks, 129 does, and 87 kids. Mapandan reported the highest population with 34 goats, including 6 bucks, 13 does, and 15 kids. In contrast, Mamonit reported the lowest count with only 2 goats, consisting of 1 buck and 1 doe. Additionally, all goats surveyed were classified as native breeds. This distribution aligns with existing literature that emphasizes the predominance of smallholder farming systems within the Philippine livestock sector. According to the Philippine Statistics Authority (2023), smallholder farms account for approximately 99.3% of the country's goat population manage around farms, underscoring the critical role that these agricultural operations play in local economies and food security.

**TABLE 4**
**INVENTORY AND BREED OF RUMINANT POPULATION SURVEYED FARMS IN MAYANTOC, TARLAC**

| Barangay | Small Ruminant (Goat) | | | |
|---|---|---|---|---|
| | Buck | Doe | Kid | TOTAL |
| Maniniog | 1 | 15 | 6 | 22 |
| Baybayaoas | 2 | 4 | 1 | 7 |
| Mapandan | 6 | 13 | 15 | 34 |
| San Jose | 1 | 3 | 1 | 5 |
| Mamonit | | 1 | 1 | 2 |
| San Bartolome | 1 | 4 | 6 | 11 |
| Carabaon | 2 | 2 | 1 | 5 |
| Ambalinguit | 3 | 16 | 1 | 20 |
| Pob. Sur | 1 | 3 | 4 | 8 |
| Cubcub | 2 | 4 | 2 | 8 |
| Gayong-Gayong | 4 | 15 | 8 | 27 |
| Gossood | 2 | 9 | 10 | 21 |
| Pitombayog | 4 | 15 | 14 | 33 |
| Binbinaca | 7 | 10 | 12 | 29 |
| Labney | 4 | 7 | 1 | 12 |
| Nambalan | 10 | 8 | 4 | 22 |
| **TOTAL** | **50** | **129** | **87** | **266** |
| **BREED** | **NATIVE** | | | **266** |

### 3.5 Sex of Respondents:

Table 5 shows the gender of the 35 respondents across various barangays, with a 19 male respondents and 16 female respondents. The male participants were from Maniniog, Baybayaoas, Mapandan, San Bartolome, Carabaoan, Ambaliguit, Pob. Sur, Cubcub, Gayong-Gayong, Gossood, Pitombayog, Binbinca, and Labney. Meanwhile, barangays Nambalan, San Jose, Mamonit, Maniniog, Baybayaoas, Mapandan, San Bartolome, Carabaoan, Ambaliguit, Pob. Sur, Cubcub, Gayong-Gayong, Gossood, Pitombayog, and Binbinca had female respondents.

**TABLE 5**
**SEX OF RESPONDENTS**

| Sex | Frequency | Percentage |
|---|---|---|
| Male | 19 | **54.29** |
| Women | 16 | **45.71** |
| **Total** | **35** | **100** |

### 3.6 Marital Status of Respondents:

Table 6 shows the marital status of respondents across various barangays. This included 74.29% married individuals, 22.86% single individuals and 2.86% that were widow/er. Respondents who were married were from the following barangays: Maniniog, Baybayaoas, Mapandan, San Jose, Mamonit, San Bartolome, Carabaon, Pob. Sur, Cubcub, Gayong Gayong, Gossood, Binbinaca, Pitombayog, and Labney. Respondents that were single were from: Maniniog, Mapandan, San Jose, Ambaliguit, Gosood and Nambalan. Meanwhile, one respondent from Nambalan was a widow. According to the Philippine Statistics Authority (PSA) in 2022, a total of 50,633 marriages were recorded in Central Luzon.

**TABLE 6**
**MARITAL STATUS OF RESPONDENTS**

| Marital Status | Frequency | Percentage |
|---|---|---|
| Single | 8 | **22.86** |
| Married | 26 | **74.29** |
| Widow/Widower | 1 | **2.86** |
| **Total** | **35** | **100** |

### 3.7 Respondents:

Table 7 shows that the age distribution of respondents across selected barangays in Mayantoc, Tarlac, demonstrated extensive variability, with ages ranging from as young as 24 years old (from Ambalinguit) to 69 years old (from Mapandan). Notable concentrations of older individuals were found in Barangays Mapandan, San Bartolome, Mamonit and Gayong-Gayong suggesting a substantial elderly population that may have required targeted community services and healthcare resources. Conversely, younger respondents were concentrated in Ambalinguit, with additional younger individuals in Cubcub (26 years). The age profile across other barangays, including Pob. Sur (30 years), Pitombayog (40 years), Maniniog (54 years), and Labney (56 years old) indicated a balanced demographic distribution.

**TABLE 7**
**AGE OF RESPONDENTS**

| Age Group | Frequency | Percentage |
|---|---|---|
| 21-30 | 7 | **20** |
| 31-40 | 7 | **20** |
| 41-50 | 7 | **20** |
| 51-60 | 10 | **28.57** |
| 61-70 | 4 | **11.43** |
| **Total** | **35** | **100** |

### 3.8 Educational Attainment of Respondents:

Table 8 details the educational attainment levels across various age groups. Survey results show that the primary school level had the highest representation, accounting for 48.57% of the respondents. This category covers all age groups. Respondents who attained secondary school level made up 34.28%, while college-level category included 14.29% of the population. Lastly, 2.86% (one respondent) reported to have undergone no formal education.

**TABLE 8**
**EDUCATIONAL ATTAINMENT OF RESPONDENTS**

| Educational Attainment | Frequency | Percentage |
|---|---|---|
| Educationally unaccomplished | 1 | **2.86** |
| Primary Certificate | 17 | **48.57** |
| Secondary Certificate | 12 | **34.28** |
| College Diploma | 5 | **14.29** |
| Post-Graduate Studies | 0 | **0** |
| Training/Seminars | 0 | **0** |
| **Total** | **35** | **100** |

### 3.9 Farming Experience of Respondents:

Table 9 shows the respondents' number of years in farming. The most common farming experience was 1-5 years, representing 65.71% of the population. This was followed by 5-10 years of farming experience, with 25.71%, followed by 10-20 years of farming experience with 5.71%. Lastly, the farming experience category of 20-10 years had 2.86% (one respondent).

Respondents in selected barangays of Mayantoc, Tarlac exhibited a diverse range of farming experiences. The majority of respondents, including those from Mapandan, Binbinica, Gossood, Baybayaoas, San Jose, Ambalinguit, and Pitombayog fell within the 1-5 years of experience category, indicating a rather recent entry into agricultural practices. Nambalan stood out with a respondent possessing over 30 years of experience, reflecting extensive expertise in livestock management. Additionally, some respondents from Mapandan, Mamonit, San Bartolome, Gayong-Gayong and Labney reported 5-10 years of experience, while Maniniog had a respondent with 10-20 years of farming experience. This variability in farming experience suggests differing levels of knowledge and practice, which could influence management decisions and overall agricultural productivity within the community.

**TABLE 9**
**FARMING EXPERIENCE OF RESPONDENTS**

| Years in Farming | Frequency | Percentage |
|---|---|---|
| 1-5 years | 23 | **65.71** |
| 6-10 years | 9 | **25.71** |
| 11-20 years | 2 | **5.71** |
| 21-30 years | 1 | **2.86** |
| 31-40 years | 0 | **0** |
| **Total** | **35** | **100** |

### 3.10 Management Systems of Respondents for their Livestock:

In selected barangays of Mayantoc, Tarlac, respondents primarily utilized tethering and extensive grazing management systems (Table 10). Tethering was the dominant practice among respondents in Maniniog, Baybayaoas, San Jose, Mamonit, San Bartolome, Carabaon, Pob. Sur, Cubcub, Gayong Gayong, Gossood, Binbinaca, Pitombayog, Labney, and Nambalan, which facilitated controlled grazing and livestock movement. Only two respondents in Mapandan opted for extensive grazing systems, providing their livestock with broader grazing areas but making health monitoring more challenging, balancing resource availability with livestock productivity.

**TABLE 10**
**MANAGEMENT SYSTEM OF RESPONDENTS FOR THEIR LIVESTOCK**

| Management System | Frequency | Percentage |
|---|---|---|
| Tethering | 33 | **94.29** |
| Intensive | 0 | **0** |
| Extensive | 2 | **5.71** |
| Semi-Intensive | 0 | **0** |
| **Total** | **35** | **100** |

### 3.11 Purposive and Stratified Sampling of Snail Samples in Mayantoc, Tarlac:

Table 16 provides a purposive and stratified sample of snail samples collected from waterways adjacent to pasture areas in selected goat farms in Mayantoc, Tarlac. A total of 35 snail samples were collected using a combination of purposive and stratified sampling, with the criteria that the samples come from areas with waterways. Specifically, the barangays of Maniniog, Baybayaoas, Mapandan, San Jose, Mamonit, San Bartolome, Carabaon, Ambaliguit, Pob. Sur, Cubcub, Gayong-Gayong, Gossood, Binbinaca, Pitombayog, Labney, and Nambalan were included. The consistency in sampling efforts across these barangays ensured equal representation in the study. The total sample size of 35 provided comprehensive data to analyze potential snail carriers responsible for spreading liver fluke infections. This approach aligns with the findings of Perez-Saez *et al.* (2019), who demonstrated the effectiveness of purposive and stratified sampling in monitoring snail populations.

**TABLE 16**
**PURPOSIVE AND STRATIFIED SAMPLING OF SNAIL SAMPLES IN MAYANTOC, TARLAC**

| Barangay | No. of Snail Sample Collected | Percentage |
|---|---|---|
| Maniniog | 2 | 5.71 |
| Baybayaoas | 2 | 5.71 |
| Mapandan | 6 | 17.14 |
| San Jose | 2 | 5.71 |
| Mamonit | 1 | 2.86 |
| San Bartolome | 1 | 2.86 |
| Carabaon | 2 | 5.71 |
| Ambaliguit | 2 | 5.71 |
| Pob. Sur | 2 | 5.71 |
| Cubcub | 2 | 5.71 |
| Gayong-Gayong | 1 | 2.86 |
| Gossood | 3 | 8.57 |
| Binbinaca | 3 | 8.57 |
| Pitombayog | 2 | 5.71 |
| Labney | 2 | 5.71 |
| Nambalan | 2 | 5.71 |
| **Total** | **35** | **100** |

### 3.12 Result of the Cathepsin B RT-LAMP Test Kit Analysis of Snail sample Collected from Selected Barangays in Mayantoc, Tarlac:

Table 17 details the results from a Cathepsin B RT-LAMP test kit analysis conducted on snail samples collected from various barangays in Mayantoc, Tarlac. All samples from the different Barangays tested negative for liver fluke, indicating no detectable levels of the parasite. This outcome may be attributed to the deworming programs (both oral and injectable) implemented by DA-LGU Mayantoc.

**TABLE 17**
**RESULT OF THE CATHEPSIN B RT-LAMP TEST KIT ANALYSIS OF SNAIL SAMPLE COLLECTED IN SELECTED BARANGAYS OF MAYANTOC, TARLAC**

| Barangay | Results |
|---|---|
| Maniniog | Negative |
| Baybayaoas | Negative |
| Mapandan | Negative |
| San Jose | Negative |
| Mamonit | Negative |
| San Bartolome | Negative |
| Carabaon | Negative |
| Ambaliguit | Negative |
| Pob. Sur | Negative |
| Cubcub | Negative |
| Gayong-Gayong | Negative |
| Gossood | Negative |
| Binbinaca | Negative |
| Pitombayog | Negative |
| Labney | Negative |
| Nambalan | Negative |

## IV. CONCLUSION

1. The study included 35 backyard farmers (19 men and 16 women), with 74.29% married, 22.86% single, and 2.86% widowed. Respondents ranged from 24 to 69 years old. The range of educational levels shows a clear trend: the majority, 48.57%, have attained primary education. Following this, secondary education accounts for 34.28%, while 14.29% have pursued college education. Only a small group, 2.86%, have no formal education. This distribution highlights the significant emphasis on primary education within the population. Farming experience showed 65.71% had 1-5 years, 25.71% had 5-10 years, 5.71% had 10-20 years, and 2.86% had over 30 years. All the respondents reported a lack of awareness about liver fluke and its implications, indicating a critical need for targeted educational initiatives. The assessment highlighted a complete lack of knowledge among respondents regarding snail sampling, liver fluke-related activities, and seminars, with all 35 respondents indicating unawareness. Additionally, all respondents were unprepared regarding the transmission vectors of liver fluke, particularly the role of snails and environmental factors.

2. The assessment of management practices among ruminant smallhold farmers in Mayantoc, Tarlac, revealed that tethering is the predominant method used. This practice was prevalent in barangays such as Maniniog, Baybayaoas, San Jose, Mamonit, San Bartolome, Carabaon, Pob. Sur, Cubcub, Gayong Gayong, Gossood, Binbinaca, Pitombayog, Labney, and Nambalan. Tethering facilitates controlled grazing and movement of livestock, helping to manage grazing areas efficiently and prevent overgrazing. Additionally, specific areas within these barangays have been identified as suitable for different management systems based on the practices of the respondents. While tethering emerged as the most common method, practiced by 94.29% of respondents, only 5.71% from Mapandan utilized an extensive grazing system, which allows livestock to roam freely over larger areas.

3. Results on the Cathepsin B RT-LAMP test showed no presence of liver fluke in Mayantoc, Tarlac. Therefore, it can be said that Mayantoc is a liver fluke free town in Tarlac and safe to raise ruminants.

## CONFLICT OF INTEREST

Authors declare no Conflict of Interest.

## REFERENCES


[1] Alstedt, U., Voigt, K., Jäger, M.C., Knubben-Schweizer, G., Zablotski, Y., Strube, C., & Wenzel, C. (2022). Rumen and liver fluke infections in sheep and goats in northern and southern Germany. Animals, 12(7), 876. Https://doi.org/10.3390/ani12070876

[2] Ashoor, S.J., & Wakid, M.H. (2023). Prevalence and hepatic histopathological findings of fascioliasis in sheep slaughtered in Jeddah, Saudi Arabia. Scientific reports, 13(1). Https://doi.org/10.1038/s41598-023-33927-0

[3] Barbour, T., Cwiklinski, K., Lalor, R., Dalton, J.P., & De, C. (2021). The zoonotic helminth parasite *Fasciola hepatica*: virulence-associated cathepsin b and cathepsin l cysteine peptidases secreted by infective newly excysted juveniles (nej). Animals, 11(12), 3495–3495. Https://doi.org/10.3390/ani11123495

[4] Beesley, N.J., Caminade, C., Charlier, J., Flynn, R.J., Hodgkinson, J.E., Martinez-Moreno, A., Martinez-Valladares, M., Perez, J., Rinaldi, l., & Williams, D.J.L. (2017). *Fasciola* and fasciolosis in ruminants in Europe: identifying research needs. Transboundary and emerging diseases, 65, 199–216. Https://doi.org/10.1111/tbed.12682

[5] Byrne, A.W., Mcbride, S., Lahuerta-Marin, A., Guelbenzu, M., Mcnair, J., Skuce, R.A., & Mcdowell, S.W.J. (2016). Liver fluke (*Fasciola hepatica*) infection in cattle in Northern Ireland: a large-scale epidemiological investigation utilizing surveillance data. Parasites & vectors, 9(1). Https://doi.org/10.1186/s13071-016-1489-2

[6] Domingo, C.Y. (2024). Prepatent detection of immature Fasciola in lymnea using rt lamp. Www.academia.edu. Retrieved January 28, 2024, from https://www.academia.edu/44623412

[7] De Kock K.N, Wolmarans C.T, & Bornman, M. (2003) distribution and habitats of the snail *Lymnaea truncatula*, intermediate host of the liver fluke *Fasciola hepatica*, in South Africa. Https://hdl.handle.net/10520/ejc99543

[8] Fox, N.J., White, P.C.L., McClean, C.J., Marion, G., Evans, A., & Hutchings, M.R. (2011). Predicting impacts of climate change on *Fasciola hepatica* risk. Plos one, 6(1). Https://doi.org/10.1371/journal.pone.0016126

[9] Gordon, C.A., Acosta, L.P., Gobert, G.N., Jiz, M., Olveda, R.M., Ross, A.G., Gray, D.J., Williams, G.M., Harn, D., Li, Y., & Mcmanus, D.P. (2015). High prevalence of *Schistosoma japonicum* and *Fasciola gigantica* in bovines from northern Samar, the Philippines. Plos neglected tropical diseases, 9(2). Https://doi.org/10.1371/journal.pntd.0003108

[10] Hoyle, R.C., Rose Vineer, H., Duncan, J.S., Williams, D.J.L., & Hodgkinson, J.E. (2022). A survey of sheep and/or cattle farmers in the UK shows confusion over the diagnosis and control of rumen fluke and liver fluke. Veterinary parasitology, 312, 109812. Https://doi.org/10.1016/j.vetpar.2022.109812

[11] Hoang Quang, V., Levecke. B., Do Trung, D., Devleesschauwer, B., Vu Thi Lam, B., Goossens, K., Polman, K., Callens, S., Dorny, P., & Dermauw, V. (2024) *Fasciola spp.* In southeast Asia: a systematic review. Plos negl trop dis. 18(1):e0011904. Doi: 10.1371/journal.pntd.0011904. PMID: 38232120; PMCID: pmc10843148.

[12] Iglesias-Piñeiro, J., González-Warleta, M., Castro-Hermida, J.A., Córdoba, M., González-Lanza, C., Manga-González, Y., & Mezo, M. (2016). Transmission of *Calicophoron daubneyi* and *Fasciola hepatica* in Galicia (Spain): Temporal follow-up in the intermediate and definitive hosts. Parasites & vectors, 9(1). Https://doi.org/10.1186/s13071-016-1892-8

[13] Lalor, R., Cwiklinski, K., Calvani, N.E.D., Dorey, A., Hamon, S., Corrales, J.L., Dalton, J.P., & De Marco Verissimo, C. (2021). Pathogenicity and virulence of the liver flukes *Fasciola hepatica* and *Fasciola gigantica* that cause the zoonosis fasciolosis. Virulence, 12(1), 2839–2867. Https://doi.org/10.1080/21505594.2021.1996520

[14] Lan, Z., Yu, J., Zhang, X., Zhang, A., Deng, R., Li, B., Ly, Q., Ma, X., Gao, J., & Wang, C. (2023). Prevalence and risk factors of ovine and caprine fasciolosis in the last 20 years in China: a systematic review and meta-analysis. Animals : an open access journal from MDPI, 13(10), 1687. Https://doi.org/10.3390/ani13101687

[15] Lucas, M., Becerro-Recio, D., Serrat, J., & González-Miguel, J. (2021). Fascioliasis and Fasciolopsiasis: current knowledge and future trends. Research in veterinary science, 134, 27–35. Https://doi.org/10.1016/j.rvsc.2020.10.011

[16] Molina-Hernández, V., Mulcahy, G., Pérez, J., Martínez-Moreno, A., Donnelly, S., O'Neill, S.M., Dalton, J.P., & Cwiklinski, K. (2015). *Fasciola hepatica* vaccine: we may not be there yet but we're on the right road. Veterinary parasitology, 208(1-2), 101–111. Https://doi.org/10.1016/j.vetpar.2015.01.004

[17] Mahulu, A., clewing, C., Stelbrink, B., Chibwana, F.D. Tumwebaze, I., Stothard, J.R. & Albrecht, C. (2019). Cryptic intermediate snail host of the liver fluke *Fasciola hepatica* in Africa. Parasites vectors 12, 573 (2019). Https://doi.org/10.1186/s13071-019-3825-9

[18] Novobilský, A., Engström, A., Sollenberg, S., Gustafsson, K., Morrison, D.A., & Höglund, J. (2014). Transmission patterns of *Fasciola hepatica* to ruminants in Sweden. Veterinary parasitology, 203(3-4), 276–286. Https://doi.org/10.1016/j.vetpar.2014.04.015

[19] Odeniran, P.O., Omolabi, K.F., & Ademola, I.O. (2021). Economic impact assessment of small ruminant fasciolosis in Nigeria using pooled prevalence obtained from literature and field epidemiological data. Veterinary parasitology: regional studies and reports, 24, 100548. Https://doi.org/10.1016/j.vprsr.2021.100548

[20] Opio, L.G., Abdelfattah, E.M., Terry, J., Odongo, S., & Okello, E. (2021). Prevalence of fascioliasis and associated economic losses in cattle slaughtered at Lira municipality abattoir in northern Uganda. Animals, 11(3), 681. Https://doi.org/10.3390/ani11030681

[21] Portugaliza, H.P., Balaso, I.M.C., Descallar, J.C.B., & Lañada, E.B. (2019). Prevalence, risk factors, and spatial distribution of *Fasciola* in carabao and intermediate host in Baybay, Leyte, Philippines. Veterinary parasitology: regional studies and reports, 15, 100261. Https://doi.org/10.1016/j.vprsr.2018.100261

[22] Perez-Saez, J., Mande, T., Zongo, D., & Rinaldo, A. (2019). Comparative analysis of time-based and quadrat sampling in seasonal population dynamics of intermediate hosts of human schistosomes. Plos neglected tropical diseases, 13(12), e0007938. https://doi.org/10.1371/journal.pntd.0007938

[23] Shahzad, W., Mehmood, K., Munir, R., Aslam, W., Ijaz, M., Ahmad, R., khan, M., & Sabir, A. (2012). Prevalence and molecular diagnosis of *Fasciola hepatica* in sheep and goats in different districts of Punjab, Pakistan. In Pakistan veterinary journal (pp. 2074–7764). Retrieved January 28, 2024, from http://www.pvj.com.pk/pdf-files/32_4/535-538.pdf

[24] Talukder, S., Bhuiyan, M., Hossain, M., Uddin, M., Paul, S., & Howlader, M. (1970). Pathological investigation of liver fluke infection of slaughtered black Bengal goat in a selected area of Bangladesh. Bangladesh journal of veterinary medicine, 8(1), 35–40. Https://doi.org/10.3329/bjvm.v8i1.7717

[25] Toet, H., Piedrafita, D.M., & Spithill, T.W. (2014). Liver fluke vaccines in ruminants: strategies, progress and future opportunities. Int j parasitol. 2014 oct 15;44(12):915-27. Doi: 10.1016/j.ijpara.2014.07.011. Epub 2014 Sep 6. PMID: 25200351.

[26] Walker, S.M., Hoey, E., Fletcher, H., Brennan, G., Fairweather, I., & Trudgett, A. (2006). Stage-specific differences in fecundity over the life-cycle of two characterized isolates of the liver fluke, *Fasciola hepatica*. Parasitology, 133(02), 209. Https://doi.org/10.1017/s003118200600014x

[27] Xia, J., jiang, S., & Peng, H. (2015). Association between liver fluke infection and hepatobiliary pathological changes: a systematic review and meta-analysis. plos one, 10(7), e0132673. Https://doi.org/10.1371/journal.pone.0132673.

# Economics of Rice Production and its Effect on Household Food Security Status in Abaji Area Council of Abuja, Nigeria

Mudashir Adeola Olaitan[1]; Beatrice Itoya Oyediji[2]; Joseph Bamidele[3]; Funso Omolayo Alabuja[4]; Sennuga, S. O.[5*]

[1,5]Department of Agricultural Extension and Rural Sociology, Faculty of Agriculture, University of Abuja, FCT, P.M.B. 117, Abuja, Nigeria
[2]Department of Agricultural Extension and Rural Development, Faculty of Agriculture University of Ibadan, Nigeria
[3]Faculty of Business and Law, University of Northampton, Waterside Campus, University Drive, Northampton NN1 5PH, United Kingdom
[4]Department of Agricultural Economics, Faculty of Agriculture, University of Abuja, FCT, P.M.B. 117, Abuja, Nigeria
*Corresponding Author

Received:- 06 October 2025/ Revised:- 13 October 2025/ Accepted:- 22 October 2025/ Published: 31-10-2025
Copyright @ 2025 International Journal of Environmental and Agriculture Research
This is an Open-Access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (https://creativecommons.org/licenses/by-nc/4.0) which permits unrestricted Non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

***Abstract—*** *This study examined the Economics of Rice Production and Its Effect on Household Food Security Status in Abaji Area Council, Abuja, Nigeria. A multistage sampling technique was used to select 200 rice farmers, and data were analyzed using descriptive statistics, Net Farm Income analysis, Food Security Index, and Tobit regression model. The socio-economic results showed that the mean age of farmers was 43.6 years, with an average household size of 6.7 persons and mean farming experience of 11.8 years. About 74% were married, 58% had secondary education, and 69% belonged to cooperative societies, with an average annual income of ₦218,000. Profitability analysis revealed that rice production was viable, yielding a Net Farm Income of ₦323,142.96, Return per Naira Invested of 3.39, Operating Ratio of 0.19, and Gross Ratio of 0.30, showing efficient resource use. Food security results indicated that 62.5% of households were food secure, while 37.5% were food insecure, with a mean Food Security Index of 1.79. The Tobit model identified education level, farm size, farm income, access to credit, cooperative membership, and farming experience as significant at the 1% and 5% levels, while age and extension contact were significant at the 10% level. Marital status was not significant. Major constraints included inadequate access to credit (78%), high input costs (74.5%), poor irrigation (64%), and pest infestation (60.5%). The study concluded that rice farming is profitable and contributes positively to household food security despite key production challenges.*

***Keywords— Rice production, profitability, food security, tobit regression.***

## I. INTRODUCTION

Rice remains one of Nigeria's most important staple foods, serving as both a subsistence and cash crop, and contributing significantly to household food security and the national economy. Nigeria is Africa's largest rice producer and consumer, with domestic demand far exceeding supply due to inefficiencies in production and post-harvest systems (Etuah *et al*., 2024: Olaitan *et al*., 2025). The importance of rice production to household food security lies in its dual role as a food and income source for smallholder farmers who constitute the majority of Nigeria's rural population. However, the economic efficiency of rice production has been hindered by rising input costs, weak extension services, and climate-induced yield fluctuations. Studies have revealed that the profitability of rice farming depends heavily on access to improved inputs, mechanization, irrigation, and market access (Ogunniyi *et al*., 2021; Yusuf *et al*., 2022; Olawumi *et al*., 2025a). The introduction of policies such as the Anchor Borrowers' Programme and the National Rice Development Strategy aimed to enhance productivity and reduce imports, yet their effectiveness in achieving sustainable food security remains mixed due to regional disparities and limited farmer inclusion (Ojehomon *et al*., 2020; Olawunmi *et al*., 2025b). As Etuah *et al*. (2024) note, resilience-building in the agricultural sector is crucial to mitigating long-term yield declines and ensuring income stability for vulnerable farming households facing climatic and economic shocks.

The economics of rice production directly influence household food security by affecting income distribution, employment generation, and access to affordable food. Empirical studies indicate that households engaged in profitable rice production exhibit higher food security status compared to non-farming households (Adenegan & Adewuyi, 2021; Awoyemi *et al*., 2022; Oyediji *et al*., 2025). Profitability analyses, particularly through gross margin and net farm income assessments, demonstrate that small-scale rice producers often operate with thin margins due to high costs of fertilizer, labour, and transportation (Mogues & Ayoola, 2021; Olawunmi *et al*., 2025c). Moreover, inadequate access to credit and poor infrastructural development exacerbate production inefficiencies and reduce market competitiveness. According to Nwosu *et al*. (2023), the average gross margin per hectare for smallholder rice farmers remains below regional benchmarks, suggesting that productivity gains are offset by inefficient resource allocation. Gender dynamics also play a crucial role, with female-headed households facing greater constraints in access to productive assets and extension services, leading to lower food security levels (Babatunde & Adefalu, 2020; Mato *et al*., 2025). As a result, interventions that improve farmers' economic capacity — including access to subsidized inputs, affordable financing, and extension education — have a multiplier effect on food security outcomes by enhancing both production efficiency and household consumption stability (Oyediji *et al*., 2025b).

Despite notable progress in increasing domestic rice production, Nigeria continues to face challenges in translating agricultural growth into improved food security outcomes. While the self-sufficiency ratio in rice production has improved since 2015, recurrent issues such as post-harvest losses, price volatility, and weak value chain integration persist (FAO, 2022; Kaka *et al*., 2023; Akomolafe *et al*., 2025). Empirical modelling using binary logistic regression and stochastic frontier analysis has revealed that factors such as household income, farm size, education, access to irrigation, and cooperative membership significantly determine food security status among rice-farming households (Usman *et al*., 2021; Oyotombe *et al*., 2025). Climate variability, particularly flooding and drought, further compounds the risks, threatening both yields and income stability (Etuah *et al*., 2024; Olaitan *et al*., 2025b). Addressing these challenges requires a comprehensive economic strategy that integrates productivity enhancement with social protection mechanisms. Scholars emphasize that rice production must be viewed not merely as an agricultural activity but as a strategic pathway toward rural transformation and sustainable livelihoods (Ojo *et al*., 2022; Adesina & Olagunju, 2023; Alabuja *et al*., 2025). Therefore, this study aims to evaluate the economics of rice production and its effect on household food security status in Abaji Area Council, Abuja. To accomplish this, the following objectives are put forward:

i. Describe the socio-economic characteristics of rice farming households in the study area;

ii. Determine the profitability of rice production in the study area;

iii. Examine the food security status of rice farming household in the study area;

iv. Estimate the effect of rice production on household food security status in the study area;

v. Identify the challenges associated with rice production in the study area.

## II. LITERATURE REVIEW

### 2.1 Theoretical Framework:

The theoretical foundation of this study draws upon the Production Theory. The Production Theory, rooted in neoclassical economics, posits that output is a function of various inputs such as land, labour, capital, and technology (Samuelson & Nordhaus, 2010). In this study, rice production is conceptualized as a process where smallholder farmers combine resources—land, seeds, fertilizers, and labour—to maximize output and income. The production function, often expressed as Q = f (L, K, T, M), where Q is rice output, L is labour, K is capital, T is technology, and M represents management or inputs, serves as the analytical foundation for measuring economic efficiency. According to Ogunniyi *et al*. (2021), efficient resource allocation and adoption of improved technologies significantly enhance productivity, which in turn raises income levels. However, when inputs are underutilized or misallocated—due to factors such as poor access to credit or extension services—farmers experience declining returns and lower profitability. This inefficiency directly affects their purchasing power and ability to secure adequate food, linking production performance to household food security outcomes. Thus, the Production Theory underpins the economic analysis of rice farming and its implications for welfare improvement.

### 2.2 Conceptual Framework:

The conceptual framework for this study, exploring the relationship between the independent variables and the dependent variables (household food security status) being mediated by the intervening variables. The independent variables in this study

are the main predictors or explanatory variables that determine the level of household food security, and these include socio-economic characteristics of age, education level, household size, farming experience, access to extension services, access to credit and membership of cooperative society. The intervening variables represent external or contextual factors that can either strengthen or weaken the relationship between rice production economics and food security. They include government policies and programs, environmental and climatic factors, infrastructure and market systems.

## III. MATERIALS AND METHODS

### 3.1 Study Area:

Abaji Area Council is one of the six administrative councils in Nigeria's Federal Capital Territory (FCT). Located about 58 km southwest of Abuja city, it lies between latitude 8°25′N and 8°45′N and longitude 6°45′E and 7°15′E, sharing boundaries with Kwali, Gwagwalada, Lokoja (Kogi State), and Nasarawa State (FCDA, 2023). The area covers about 1,100 km² with a population of roughly 150,000 inhabitants (NPC, 2023). The people are mainly Gwari, Bassa, Egbira, Gede, Hausa, and Fulani, and their livelihood revolves around subsistence agriculture. Abaji town serves as the administrative and commercial center, strategically located along the Abuja–Lokoja highway, facilitating easy transport of farm produce to markets (FCT-ADP, 2022).

Abaji falls within the Guinea Savannah ecological zone, characterized by a tropical climate with a wet season from April to October and an annual rainfall of 1,200–1,500 mm. Temperatures range between 26°C and 34°C, ideal for crop cultivation (NIMET, 2022). The area has loamy and alluvial soils, making it highly suitable for rice farming, particularly along river floodplains such as the Gurara River and its tributaries (Abaji Agriculture Department, 2023). Besides rice, farmers cultivate maize, cassava, yam, and vegetables, using mostly family labour and traditional tools (Ogunniyi *et al*., 2021).

The economy is largely agrarian, with over 70% of residents engaged in farming, petty trading, and agro-processing. Despite its fertile land, Abaji faces constraints such as limited access to credit, poor infrastructure, and post-harvest losses (FAO, 2022). However, proximity to Abuja city offers access to urban markets and income opportunities. Government initiatives like the Anchor Borrowers' Programme and FADAMA projects support farmers through credit and training (FCT-ADP, 2022).

Abaji is selected as the study area because it reflects the economic, environmental, and livelihood realities of smallholder rice producers in Nigeria. Its favourable agro-ecological conditions, vibrant rice-farming communities, and market linkages make it an ideal setting for analyzing how rice production economics influence household food security (FAO, 2022; Ogunniyi *et al*., 2021).

### 3.2 Population of the Study and Research Design:

The study population comprises all rice-farming households in Abaji Area Council, Abuja. These smallholder farmers cultivate between 1–3 hectares, relying on family labour and mixed production systems.

This study adopts a descriptive survey research design complemented by quantitative analysis. The descriptive survey approach is appropriate because it enables the researcher to collect data directly from farmers to describe the economic characteristics of rice production and assess its impact on household food security status (Ogunniyi *et al*., 2021). The design allows for the systematic collection of both primary and secondary data on production inputs, yield, household income, and food consumption patterns.

### 3.3 Sample Size and Sampling Techniques:

The study employed a multi-stage sampling technique to select respondents from rice-farming households in Abaji Area Council of the Federal Capital Territory (FCT), Nigeria. This method was chosen to ensure that farmers from various communities and production scales were adequately represented.

In the first stage, six major rice-producing communities — Agyana, Nuku, Pandagi, Yaba, Rimba, and Abaji town — were purposively selected based on their prominence in rice cultivation (Abaji Agriculture Department, 2023).

In the second stage, a list of registered rice farmers was obtained from the FCT Agricultural Development Programme (FCT-ADP). From this list, proportionate random sampling was applied to determine the number of respondents from each community according to the relative size of their farming population.

In the third stage, simple random sampling was used to select individual rice-farming households from each community, ensuring that every farmer had an equal chance of inclusion. A total of 200 respondents were selected as the study's sample

size. This figure was determined to provide sufficient statistical reliability and representativeness while maintaining feasibility in data collection.

The 200 respondents were distributed proportionately among the six communities as follows: Agyana (35), Nuku (30), Pandagi (35), Yaba (35), Rimba (30), and Abaji town (35). This distribution reflects the density of rice farmers in each area and ensures balanced representation across the council.

### 3.4 Data Collection:

The primary data for this study were collected using a structured questionnaire designed to obtain detailed information from rice-farming households in Abaji Area Council, Abuja. The questionnaire was administered to a representative sample of 200 farmers, with each session lasting about one hour to allow respondents ample time to provide accurate and thoughtful answers. To ensure the instrument's validity and reliability, a pilot test was conducted with a small group of rice farmers outside the main sample. Feedback from the pilot exercise helped refine question wording, structure, and relevance, ensuring that the final instrument effectively captured data on the economics of rice production and its impact on household food security. Trained enumerators were engaged to administer the questionnaires, ensuring that respondents clearly understood each question and that responses were accurately recorded.

### 3.5 Data Analysis:

Data collected from rice-farming households in Abaji Area Council were analyzed using a combination of descriptive and inferential statistical methods. Descriptive statistics such as means, frequencies, and percentages were employed to address Objectives (i) and (v) — describing the socio-economic characteristics of the farmers and identifying challenges associated with rice production.

To achieve Objective (ii), which sought to determine the profitability of rice production, the Net Farm Income (NFI) model was used. For Objective (iii), the Food Security Index (FSI) was constructed to assess the food security status of rice-farming households. To address Objective (iv), which estimated the effect of rice production on household food security, the Tobit regression model was applied, capturing both the intensity and likelihood of household food security.

All analyses were conducted using the Statistical Package for the Social Sciences (SPSS) version 24, which provided a reliable platform for both descriptive and econometric analyses, ensuring accuracy and robustness in data interpretation.

### 3.6 Model Specification:

#### 3.6.1 Net Farm Income (NFI) Model:

The Net Farm Income model was employed to determine the profitability of rice production in the study area. It is expressed as:

$$NFI = TR - TC \quad (1)$$

Where:

NFI = Net Farm Income (₦)

TR = Total Revenue (₦)

TC = Total Cost of Production (₦)

The total cost (TC) comprises both variable and fixed costs, given as:

$$TC = TVC + TFC \quad (2)$$

Where:

TVC = Total Variable Cost (₦)

TFC = Total Fixed Cost (₦)

Fixed assets such as tractors and sprayers were depreciated using the straight-line method:

$$D = \frac{P-S}{N} \quad (3)$$

Where:

D = Depreciation (₦), P = Purchase Value (₦), S = Salvage Value (₦), and N = Life Span (years).

The Return per Naira Invested (RNI) was obtained as:

$$GNI = \frac{GI}{TC} \quad (4)$$

Where

GI = Gross Income (₦) and TC = Total Cost (₦).

Decision Rule:

- If RNI > 1, the enterprise is profitable.
- If RNI = 1, the farmer breaks even.
- If RNI < 1, the farmer incurs a loss.

The Gross Ratio (GR), indicating cost efficiency, was calculated as:

$$GR = \frac{TC}{GI} \quad (5)$$

### 3.6.2 Food Security Index (FSI):

To measure household food security (Objective iii), a Food Security Index was constructed following identification and aggregation procedures. The food security line represents the minimum daily calorie intake required for healthy living. Households consuming below this line were classified as food insecure. The model is given as:

$$Z_i = \frac{X}{Y} \quad (6)$$

Where:

Zi = Food Security Index,

X = Per capita calorie available per day,

Y = Recommended per capita calorie intake per day.

Decision Rule:

- If Zi ≥ 1: Household is food secure.
- If Zi < 1: Household is food insecure.

### 3.6.3 Tobit Regression Model:

To evaluate the effect of rice production on household food security status (Objective iv), a Tobit regression model was applied due to its suitability for censored dependent variables. The model is expressed as:

$$Y_i = X_i\beta + \varepsilon_i \quad (7)$$

Where:

Yi = Food Security Index of the *i-th* household,

Xi = Vector of independent variables,

β = Vector of parameters to be estimated,

εi = Error term

The explicit form of the model is:

$$Yi=\beta0 + \beta1X1 + \beta2X2 + \beta3X3 + \beta4X4 + \beta5X5 + \beta6X6 + \beta7X7 + \beta8X8 + \beta9X9 + \beta10X10 + \beta11X11 + \mu i \quad (8)$$

Where:

X1 = Output of rice (kg),

X2 = Age of household head (years),

X3 = Marital status,

X4 = Education level (years),

X5 = Household size,

X6 = Farm size (ha),

X7 = Farming experience (years),

X8 = Membership of association,

X9 = Access to credit (₦),

X10 = Off-farm income (₦),

X11 = Extension contact frequency,

μi = Error term.

## IV. RESULTS AND DISCUSSION

### 4.1 Socio-Economic Characteristics of Rice Farmers:

The results in Table 1 show that the mean age of rice farmers was 43.6 years, indicating that most are in their economically active years. About 35% were between 40–49 years, suggesting an experienced and productive group capable of managing farm activities efficiently. This finding aligns with Ogunniyi *et al.* (2021), who noted that rice farming in Nigeria is dominated by middle-aged farmers with both energy and experience.

Marital status distribution revealed that 74% were married, while 16% were single and 10% widowed or divorced. This shows that rice farming households are mostly family-based. Ojo *et al*. (2020) observed similar trends, stating that married farmers often have higher labour availability and social stability that support agricultural productivity.

Farming experience among respondents averaged 11.8 years, with 60% having over six years of engagement. This indicates that most farmers have acquired substantial practical knowledge and farming skills. This result is consistent with Akinbode and Rahji (2020), who emphasized that long years of experience improve farmers' adaptation to production challenges and market conditions.

Regarding educational status, 41% of respondents had secondary education, 28% primary, 17% tertiary, while 14% had no formal education. This suggests a moderately literate farming population. Ogunlela and Mukhtar (2021) noted that education significantly influences decision-making, technology use, and resource management among smallholder farmers, thus improving farm productivity and efficiency.

The average household size was 6.7 persons, indicating relatively large families. About 45% of respondents had 4–6 members. Larger households provide readily available family labour, which is beneficial during peak farming periods. Nwaobiala and Nwosu (2020) observed that household size directly affects both labour supply and food demand in rural Nigerian households.

Access to credit was relatively moderate, with 64% of farmers having received some financial assistance. The average credit amount accessed was ₦68,400. Access to credit enables farmers to purchase inputs such as improved seeds and fertilizers, enhancing productivity. Ogunleye *et al.* (2021) reported that collateral requirements and high interest rates often restrict smallholders' access to agricultural loans in Nigeria.

Access to extension services was found to be moderate, with 71% of respondents having at least one contact per season and an average of 2.3 visits. This contact frequency is below the recommended level for effective information dissemination. FMARD (2022) emphasized that frequent extension interactions enhance knowledge transfer, but limited visits can reduce the impact of advisory services.

About 69% of farmers belonged to cooperatives, with an average membership duration of 4.1 years. Afolami *et al*. (2019) found that cooperative participation improves farmers' welfare and access to agricultural support programs, thus strengthening their resilience to market fluctuations.

The average annual farm income was ₦218,500, with 37% earning between ₦100,000 and ₦199,999. The results reflect the smallholder nature of rice farming in Abaji. FAO (2022) and Ogunniyi *et al*. (2021) observed similar patterns, noting that income levels among smallholder farmers are influenced by limited scale, market constraints, and production costs.

**TABLE 1**

**SOCIO-ECONOMIC CHARACTERISTICS OF RICE FARMERS (n = 200)**

| Variable | Freq (n = 200) | Percentage |
|---|---|---|
| **Educational level** | | |
| No formal education | 28 | 14 |
| Primary school | 56 | 28 |
| Secondary school | 82 | 41 |
| Tertiary education | 34 | 17 |
| **Marital Status** | | |
| Single | 32 | 16 |
| Married | 148 | 74 |
| Widowed/Divorced | 20 | 10 |
| **Age (Mean = 43.6 years)** | | |
| 20 – 29 years | 26 | 13 |
| 30 – 39 years | 58 | 29 |
| 40 – 49 years | 70 | 35 |
| 50 and above | 46 | 23 |
| **Years of farming Experience (Mean = 11.8 years)** | | |
| 1–5 | 40 | 20 |
| 6–10 | 68 | 34 |
| 11–15 | 52 | 26 |
| 16 and above | 40 | 20 |
| **Household Size (Mean = 6.7 people)** | | |
| 1–3 | 24 | 12 |
| 4–6 | 90 | 45 |
| 7–9 | 60 | 30 |
| ≥10 | 26 | 13 |
| **Cooperative Membership (Mean = 4.1 years)** | | |
| None | 62 | 31 |
| 1–3 | 54 | 27 |
| 4–6 | 52 | 26 |
| Above 6 | 32 | 16 |
| **Amount of Credit Received (Mean = ₦68,400)** | | |
| None | 72 | 36 |
| ₦1 – ₦50,000 | 56 | 28 |
| ₦51,000 – ₦100,000 | 44 | 22 |
| Above ₦100,000 | 28 | 14 |
| **Farm Income of Household Heads (Mean = ₦218,000)** | | |
| ₦50,000 – ₦99,999 | 38 | 19 |
| ₦100,000 – ₦199,999 | 74 | 37 |
| ₦200,000 – ₦299,999 | 58 | 29 |
| ₦300,000 and above | 30 | 15 |
| **Extension Visits per Season (Mean = 2.3 times)** | | |
| None | 58 | 29 |
| 1–2 | 86 | 43 |
| 3–4 | 38 | 19 |
| 5 and above | 18 | 9 |

***Source: Field Survey, 2025***

### 4.2 Profitability of Rice Production:

The results in Table 2 show that rice production in Abaji Area Council is a profitable agricultural enterprise. The total production cost per hectare was estimated at ₦135,378.14, consisting of ₦85,551.99 in variable costs and ₦49,826.15 in fixed costs. Variable costs constituted 60.5% of the total, while fixed costs accounted for 35.3%, indicating that rice farming is relatively labour- and input-intensive. Similar cost structures were observed by Ogunniyi *et al*. (2021) and Akinbode and Rahji (2020), who found that variable inputs dominate production expenditure in smallholder rice systems in Nigeria.

Among the variable cost components, labour accounted for the largest share (₦36,940.25, or 26.1% of total cost), reflecting the labour-intensive nature of rice cultivation. The heavy reliance on manual labour underscores the limited mechanization in smallholder rice farming systems, a pattern also noted by FAO (2022).

Fertilizer and agrochemical costs were ₦12,150.00 (8.6%) and ₦9,360.80 (6.6%), respectively. Rising fertilizer prices and inadequate input subsidies continue to affect smallholder profitability, as observed by Ogunleye *et al*. (2021) and FMARD (2022).

The fixed cost component amounted to ₦49,826.15 per hectare, dominated by land rent or lease cost (₦32,490.60; 23.0%) and machinery depreciation (₦9,620.20; 6.8%). This reflects the increasing cost of land acquisition and the use of hired or depreciated machinery for tilling and harvesting. Similar fixed cost patterns were reported by Ojo *et al*. (2020), who noted that land rent constitutes the largest non-variable cost in irrigated and upland rice systems.

In terms of returns, rice farmers recorded an impressive gross income (GI) of ₦458,521.10 per hectare, derived from sales (₦385,460.70; 84.1%), household consumption (₦44,370.00; 9.7%), and gifts or transfers (₦28,690.40; 6.2%). This mirrors the findings of Nwaobiala and Nwosu (2020), who observed that farm produce retained for household consumption significantly contributes to rural food security.

The gross margin stood at ₦372,969.11 per hectare, while the net farm income was ₦323,142.96 per hectare. This positive net return indicates that rice production in Abaji Area Council is economically viable. The return per naira invested (3.39) means that for every ₦1 spent on rice farming, a return of ₦3.39 was earned, suggesting high profitability and efficient resource use. This aligns with results from Afolami *et al*. (2019) and Ogunniyi *et al*. (2021), who reported positive returns among smallholder rice producers in Nigeria.

The operating ratio (0.19) and fixed ratio (0.11) further demonstrate cost efficiency. The low operating ratio implies that only 19% of total revenue is used to cover variable expenses, leaving a large portion as potential profit. The gross ratio (0.30), which measures the proportion of total cost to gross income, indicates a favourable cost-to-income relationship. According to FAO (2022), a gross ratio below 1 signifies profitability, and a lower value reflects better financial performance; hence, rice production in Abaji shows strong financial sustainability.

**TABLE 2**
**AVERAGE COSTS AND RETURNS PER HECTARE OF RICE PRODUCTION**

| Items of Cost | Average Value (₦/ha) | Percentage (%) |
|---|---|---|
| **Variable Cost** | | |
| Seed and Seedlings | 13,820.50 | 9.8 |
| Labour (land preparation, planting, weeding, irrigation, harvesting, threshing) | 36,940.25 | 26.1 |
| Fertilizers | 12,150.00 | 8.6 |
| Agrochemicals (herbicides, pesticides, etc.) | 9,360.80 | 6.6 |
| Transportation (input and produce movement) | 13,280.45 | 9.4 |
| **Total Variable Cost (TVC)** | **85,551.99** | **60.5** |
| **Fixed Cost** | | |
| Land Rent/Lease | 32,490.60 | 23 |
| Farm Equipment and Machinery Depreciation | 9,620.20 | 6.8 |
| Storage and Maintenance Costs | 7,715.35 | 5.5 |
| **Total Fixed Cost (TFC)** | **49,826.15** | **35.3** |
| **Total Cost (TC)** | **135,378.14** | **100** |
| **Returns** | | |
| Sales Revenue | 385,460.70 | 84.1 |
| Household Consumption Value | 44,370.00 | 9.7 |
| Gifts/Transfers | 28,690.40 | 6.2 |
| **Gifts/Transfers** | **28,690.40** | **6.2** |
| **Gross Income (GI)** | **458,521.10** | **100** |
| **Gross Margin (GI – TVC)** | **372,969.11** | **—** |
| **Net Farm Income (GI – TC)** | **323,142.96** | **—** |
| **Return per Naira Invested (GI ÷ TC)** | **3.39** | **—** |

***Source: Field Survey, 2025***

### 4.3 Household Food Security Status among Rice-Farming Households:

The findings presented in Table 3 show that a majority of the rice-farming households in Abaji Area Council were food secure. Out of the 200 sampled households, 62.5% were classified as food secure, while 37.5% were food insecure. The food security index of 1.79 for the food-secure group indicates that their daily calorie intake was about 79% higher than the recommended 2,260 Kcal per adult equivalent. In contrast, food-insecure households recorded a food insecurity index of 0.49, revealing that their calorie intake was 51% below the threshold for maintaining a healthy diet. This contrast suggests that food insecurity remains a major challenge among smallholder rice producers, echoing findings by Ogunniyi *et al*. (2021) and FAO (2022) that disparities in agricultural productivity and access to income significantly influence rural household food sufficiency.

The average daily calorie intake for food-secure households was 4,095.48 Kcal, exceeding the required level by 1,835.48 Kcal, while food-insecure households consumed only 1,085.26 Kcal per day. The calorie surplus index of 0.79 among secure households compared with the calorie deficiency index of 0.51 for insecure households underscores the nutritional divide between these groups. The average rice output of 8,215.33 kg for food-secure households against 1,605.42 kg for food-insecure ones illustrates that higher productivity translates directly to improved food access and consumption (Okunola *et al*., 2020).

Income levels also reinforce this pattern. The average annual income of food-secure households (₦658,720.65) was nearly three times higher than that of food-insecure households (₦242,189.37), demonstrating the critical role of economic capacity in ensuring food sufficiency. According to Obayelu *et al*. (2019) and Akinyele (2021), households with greater financial resources can better afford diverse and adequate diets, even during periods of production shortfall or market price fluctuations.

In general, the results affirm a strong interrelationship between rice production, income, and food security status. Households with higher yields and greater financial returns experienced better food access, nutritional intake, and overall well-being.

Conversely, those with limited resources and lower productivity faced persistent food insecurity. These findings are consistent with studies by Amaza *et al*. (2020) and FAO (2022), which emphasize that improving agricultural output and income levels significantly enhances household food security in rural Nigeria.

**TABLE 3**
**FOOD SECURITY ANALYSIS OF RICE-FARMING HOUSEHOLDS IN ABAJI AREA COUNCIL**

| Variable (Average Values) | Value |
|---|---|
| **Food-secure households (No.)** | 125 |
| Household food security index | 1.79 |
| Calorie surplus index | 0.79 |
| Average daily calorie intake per food-secure household (Kcal) | 4,095.48 |
| Average calorie intake above recommended level (2,260 Kcal) | 1,835.48 |
| Average total rice output per food-secure household (kg) | 8,215.33 |
| Average annual income of food-secure household (₦) | 658,720.65 |
| Proportion of food-secure households (%) | 62.5 |
| **Food-insecure households (No.)** | 75 |
| Household food insecurity index | 0.49 |
| Calorie deficiency index | 0.51 |
| Average daily calorie intake per food-insecure household (Kcal) | 1,085.26 |
| Average calorie shortfall from recommended level (2,260 Kcal) | 1,174.74 |
| Average total rice output per food-insecure household (kg) | 1,605.42 |
| Average annual income of food-insecure household (₦) | 242,189.37 |
| Proportion of food-insecure households (%) | 37.5 |

***Source: Field Survey, 2025***

### 4.4 Factors Influencing Household Food Security Status among Rice Farmers:

The Tobit model summary in Table 4 indicates a good overall fit, with a Log Likelihood of -94.357 and an LR Chi-Square value of 42.816 significant at $p < 0.01$, confirming the joint significance of all explanatory variables. The Pseudo $R^2$ of 0.312 suggests that approximately 31.2% of the variation in household food security status among rice farmers is explained by the included variables, demonstrating a moderately strong explanatory power suitable for cross-sectional household data.

Education showed a positive and significant relationship ($\beta = 0.028$; $p < 0.01$) with household food security. This implies that better-educated farmers are more efficient in resource use, financial management, and adoption of modern farming techniques. The result supports Ogunniyi *et al*. (2021), who found that education improves household welfare and dietary adequacy among farming families in Nigeria.

Farm size positively influenced food security ($\beta = 0.152$; $p < 0.01$), signifying that larger farms generate higher output and income, improving food availability. FAO (2022) similarly identified farm size as a critical determinant of household food security through its direct link to agricultural productivity.

Farm income ($\beta = 0.000021$; $p < 0.01$) was highly significant, confirming that higher income levels lead to improved food security. This aligns with Obayelu *et al*. (2019), who established that income growth is directly associated with enhanced food availability and nutritional sufficiency among Nigerian farmers.

Household size had a negative and significant coefficient (-0.022; $p < 0.05$), implying that larger households are more prone to food insecurity due to higher dependency ratios and consumption pressures. This is consistent with Obayelu *et al*. (2019), who reported that smaller households tend to achieve better food sufficiency levels in rural Nigeria.

The coefficient for farming experience (0.009) was significant at the 5% level, showing that experienced farmers are more food secure. This agrees with Okunola *et al*. (2020), who found that experience positively affects productivity and food access among crop producers.

Cooperative membership was significant at the 5% level ($\beta = 0.018$), indicating that longer involvement in cooperatives enhances food security. This corroborates Akinyele (2021), who noted that cooperatives strengthen farmers' resilience and resource access, leading to better food security outcomes.

Access to credit (β = 0.000012; p < 0.05) had a positive and significant impact, demonstrating that credit availability enables farmers to invest in inputs, machinery, and better farm management practices. Olayemi *et al*. (2020) affirmed that credit access mitigates liquidity constraints and stabilizes food supply among farming households.

The coefficient for age (-0.013) was significant at the 10% level, indicating a negative relationship between farmers' age and household food security. This finding aligns with Amaza *et al*. (2020), who observed that younger farmers are more likely to adopt improved technologies, enhancing food security outcomes.

The coefficient for extension contact (0.036) was positive and significant at 10%, suggesting that interaction with extension officers enhances food security. Alabi and Arinola (2022) also found that frequent extension visits significantly increase adoption rates of high-yield technologies among rural farmers.

Marital status had a positive but statistically insignificant coefficient (0.054), suggesting that whether a farmer is married or not had minimal effect on household food security. Olayemi *et al*. (2020) similarly found that marital status exerted no substantial influence on household food consumption levels among Nigerian smallholders.

**TABLE 4**

**TOBIT REGRESSION ESTIMATES OF FACTORS INFLUENCING HOUSEHOLD FOOD SECURITY STATUS AMONG RICE FARMERS**

| Variable | Coefficient (β) | Standard Error | t-value | p-value | Significance |
|---|---|---|---|---|---|
| Constant | 0.842 | 0.217 | 3.88 | 0 | *** |
| Age (years) | -0.013 | 0.007 | -1.86 | 0.065 | * |
| Marital Status (1 = Married, 0 = Otherwise) | 0.054 | 0.034 | 1.58 | 0.116 | NS |
| Educational Level (years) | 0.028 | 0.01 | 2.8 | 0.006 | *** |
| Household Size (No.) | -0.022 | 0.009 | -2.44 | 0.016 | ** |
| Farming Experience (years) | 0.009 | 0.004 | 2.25 | 0.026 | ** |
| Farm Size (hectares) | 0.152 | 0.044 | 3.45 | 0.001 | *** |
| Cooperative Membership (years) | 0.018 | 0.009 | 2 | 0.048 | ** |
| Contact with Extension Agents (No.) | 0.036 | 0.02 | 1.8 | 0.073 | * |
| Access to Credit (₦) | 0.000012 | 0.000005 | 2.4 | 0.018 | ** |
| Farm Income (₦) | 0.000021 | 0.000007 | 3 | 0.003 | *** |
| **Model Statistics** | | | | | |
| Log Likelihood = -94.357 | | | | | |
| LR Chi-Square (10) = 42.816 | | | | | |
| Prob > Chi-Square = 0.000 | | | | | |
| Pseudo $R^2$ = 0.312 | | | | | |

**Note:** ***, ** and * indicate significance at 1%, 5% and 10% probability level respectively; NS = Not Significant

***Source: Field Survey, 2025***

### 4.5 Constraints to Rice Production among Farmers:

The results in Table 5 identify the major constraints affecting rice production among farmers in Abaji Area Council. The most pressing challenge reported was inadequate access to credit facilities (78%), which restricts farmers' ability to purchase quality inputs, hire labour, and invest in modern technologies. Limited access to affordable financing has long been recognized as a key bottleneck in smallholder agriculture across Nigeria (Ogunniyi *et al*., 2021).

The high cost of farm inputs (74.5%) ranked second, reflecting the rising prices of fertilizers, agrochemicals, and improved seeds, which directly reduce profitability and productivity. This supports findings by FAO (2022) that escalating input costs limit production efficiency among smallholder farmers. Similarly, poor access to irrigation and water supply (64%) was identified as a major issue, exposing farmers to rainfall dependency and the effects of climate variability.

Pest and disease infestation (60.5%) also emerged as a significant challenge, leading to yield losses and increased production costs. Limited access to extension services (54.5%) constrains farmers' exposure to improved agronomic practices and innovations, while poor road and market infrastructure (51.5%) hinders transportation and timely marketing of produce, increasing post-harvest losses. Additionally, inadequate storage facilities (48%) contribute to grain deterioration and income loss after harvest.

**TABLE 5**

**CONSTRAINTS TO RICE PRODUCTION AMONG FARMERS IN ABAJI AREA COUNCIL**

| Constraints to Rice Production | Frequency | Percentage (%) |
|---|---|---|
| Inadequate access to credit facilities | 156 | 78 |
| High cost of farm inputs (fertilizers, chemicals, seeds) | 149 | 74.5 |
| Poor access to irrigation and water supply | 128 | 64 |
| Pest and disease infestation | 121 | 60.5 |
| Limited access to extension services | 109 | 54.5 |
| Poor road and market infrastructure | 103 | 51.5 |
| Post-harvest losses and inadequate storage facilities | 96 | 48 |

***Source: Field Survey, 2025***

## V. CONCLUSION AND RECOMMENDATIONS

The study on the Economics of Rice Production and Its Effect on Household Food Security Status in Abaji Area Council, Abuja revealed important empirical insights across socio-economic characteristics, profitability, food security, influencing factors, and production constraints among rice farmers.

The socio-economic profile indicated that the mean age of farmers was 43.6 years, implying that most were within their productive age. The majority (74%) were married, with an average household size of 6.7 persons, and farming experience of 11.8 years. Most farmers (58%) had attained at least secondary education, while 69% were members of cooperative societies and 71% had access to extension services, though the mean number of extension contacts was low (2.3 per season). The average annual farm income was ₦218,000, indicating modest economic performance within a smallholder context.

Profitability analysis revealed that rice production was economically viable. The average total cost per hectare was ₦ 135,378.14, resulting in a net farm income of ₦323,142.96. The Return per Naira Invested (RNI) was 3.39, indicating that every ₦1 invested yielded ₦3.39 profit. The Operating Ratio (0.19) and Gross Ratio (0.30) also confirmed the profitability of rice production in the area.

The food security analysis showed that 125 households (62.5%) were food secure, while 75 households (37.5%) were food insecure. The mean Food Security Index (FSI) was 1.79, indicating that the average household met the daily recommended calorie intake.

The Tobit regression results identified educational level, farm size, farm income, access to credit, cooperative membership, and farming experience significantly and positively influenced the household food security index at 1% and 5% levels. In contrast, age and extension contact were significant at the 10% level, indicating weaker but still relevant effects. Marital status was not statistically significant, implying limited influence on food security outcomes.

Finally, the major constraints to rice production identified were inadequate access to credit (78%), high cost of inputs (74.5%), poor irrigation (64%), pest and disease infestation (60.5%), limited extension access (54.5%), poor infrastructure (51.5%), and post-harvest losses (48%).

Based on the findings of the study, the following recommendations are made to enhance productivity, profitability, and household food security among rice farmers:

1. Government and financial institutions should develop farmer-friendly credit schemes with low interest rates and flexible repayment terms. This will enable smallholder rice farmers to acquire necessary inputs and technologies to expand production efficiently.
2. The cost of fertilizers, improved rice seeds, herbicides, and machinery should be subsidized or made available through cooperative societies to reduce production costs and improve profitability.
3. Extension agents should increase their coverage and frequency of contact with farmers. Regular training on improved agronomic practices, pest management, and post-harvest handling should be institutionalized to boost yields and food security.
4. Government should invest in irrigation facilities, rural roads, and market infrastructure to enhance year-round rice production, reduce post-harvest losses, and facilitate access to input and output markets.

Adult education and training programs should be introduced to improve the literacy and management skills of farmers, enhancing their ability to adopt modern farming technologies and make informed production decisions.

## REFERENCES


[1] Abaji Agriculture Department. (2023). *Annual report on crop production statistics in Abaji Area Council*. Federal Capital Territory Administration.

[2] Adenegan, K. O., & Adewuyi, S. A. (2021). Economic analysis of smallholder rice production and its impact on household food security in Nigeria. *Journal of Agricultural Economics and Development, 10*(2), 45–57.

[3] Afolami, C. A., Obayelu, A. E., & Vaughan, I. I. (2019). Welfare impact of modern rice varieties adoption among smallholder farmers in Southwest Nigeria. *Agro-Science Journal of Tropical Agriculture, Food, Environment and Extension, 18*(1), 12–24.

[4] Akinbode, S. O., & Rahji, M. A. Y. (2020). Comparative profitability analysis of rice production systems in Ogun State, Nigeria. *Nigerian Journal of Agricultural Economics, 10*(1), 101–114.

[5] Akinyele, I. O. (2021). Determinants of household food security in rural Nigeria: Implications for agricultural transformation. *African Development Review, 33*(S1), S94–S108.

[6] Akomolafe, J. K., Fadiji, T.O., Barnabas, T. M. & Sennuga, S. O. (2025). Adoption of System of Rice Intensification (SRI) Methodology among Rice Farmers in Nasarawa State, Nigeria *International Journal of Environmental and Agriculture Research.* 11(7):167-177

[7] Alabi, O. O., & Arinola, A. A. (2022). Extension contact and its effect on the adoption of rice production technologies in Southwestern Nigeria. *Journal of Extension Systems, 38*(2), 75–88

[8] Alabuja, F. O., Bako, H., Oyediji, B. I., Bamidele, J. & Sennuga, S.O. (2025). Evaluation of the production efficiency and profitability of groundnut production in Bwari and Gwagwalada Area Councils of Abuja, Nigeria *International Journal of Environmental and Agriculture Research,* 11 (10): 1-12

[9] Amaza, P. S., Umeh, J. C., & Olayemi, J. K. (2020). Determinants of food security among farming households in Nigeria. *Journal of Rural Development, 39*(4), 573–592.

[10] Awoyemi, T. T., Alao, A. O., & Adefalu, L. L. (2022). Economic determinants of household food security among rice producers in Kwara State, Nigeria. *International Journal of Food and Agricultural Economics, 10*(1), 29–48.

[11] Babatunde, R. O., & Adefalu, L. L. (2020). Gender dimensions of rice production and household food security in Nigeria. *Journal of Agricultural Extension, 24*(3), 54–67.

[12] Etuah, M. A., Kaka, L. A., & Ojo, F. (2024). Climate variability and the economics of rice production in Sub-Saharan Africa: Implications for food security. *African Journal of Agricultural Research, 19*(5), 210–225.

[13] FCT Agricultural Development Programme (FCT-ADP). (2022). *Annual performance report on FADAMA and Anchor Borrowers' Programme implementation in the Federal Capital Territory*. Federal Ministry of Agriculture and Rural Development.

[14] Federal Capital Development Authority (FCDA). (2023). *Abaji Area Council development profile and demographic report*. FCDA Publications.

[15] Federal Ministry of Agriculture and Rural Development (FMARD). (2022). *Agricultural extension policy implementation review report*. FMARD Publication Series.

[16] Food and Agriculture Organization (FAO). (2022). *State of food security and nutrition in Nigeria: Rural resilience and productivity*. FAO Country Report.

[17] Kaka, L. A., Etuah, M. A., & Yusuf, A. O. (2023). Post-harvest management and rice value chain efficiency in Nigeria. *Journal of Agribusiness and Rural Development, 15*(3), 88–105.

[18] Mato, J., Fadiji, T. O., Ajah, J. & Sennuga, S. O. (2025). Factors Influencing Adoption of Tme-419 Cassava Production by Farmers in the Federal Capital Territory, Nigeria. *Indiana Journal of Agriculture and Life Sciences*, 5(4), 7-6.

[19] Mogues, T., & Ayoola, G. B. (2021). Cost efficiency and input use in smallholder rice farming systems in Nigeria. *African Journal of Agricultural and Resource Economics, 16*(2), 101–118.

[20] National Population Commission (NPC). (2023). *Population census estimates and projections for the Federal Capital Territory, Abuja*. NPC Report.

[21] Nigerian Meteorological Agency (NIMET). (2022). *Annual climate report for the Federal Capital Territory*. NIMET Publications.

[22] Nwaobiala, C. U., & Nwosu, C. S. (2020). Socioeconomic determinants of rice production and food security among smallholder farmers in Abia State, Nigeria. *International Journal of Agricultural Policy and Research, 8*(4), 95–106.

[23] Nwosu, I. A., Ojo, S. O., & Olayemi, K. A. (2023). Productivity and profitability analysis of rice-based farming households in Nigeria. *Journal of Development and Agricultural Economics, 15*(2), 73–88.

[24] Obayelu, A. E., Afolami, C. A., & Olayemi, K. A. (2019). Income dynamics and food security status of farming households in rural Nigeria. *Journal of Rural Studies, 68*, 32–44.

[25] Ogunlela, Y. I., & Mukhtar, A. A. (2021). Influence of farmers' education on technology adoption and farm productivity in Northern Nigeria. *Journal of Rural and Agricultural Development, 13*(2), 144–158.

[26] Ogunleye, A. S., Yusuf, A. O., & Adeniran, L. O. (2021). Determinants of access to agricultural credit among rice farmers in Southwest Nigeria. *Nigerian Agricultural Policy Research Journal, 9*(2), 55–67.

[27] Ogunniyi, L. T., Ojo, O. T., & Ayinde, O. E. (2021). Economics of rice production and food security among smallholder farmers in Nigeria. *Nigerian Journal of Agricultural Economics, 11*(1), 120–135.

[28] Ojehomon, V. E. T., Yusuf, S. A., & Adebayo, K. (2020). Policy performance of rice intervention programs in Nigeria: The Anchor Borrowers' experience. *Journal of Agricultural Policy and Research, 15*(4), 1–17.

[29] Ojo, M. A., Abubakar, L. U., & Lawal, A. A. (2022). Rice production as a pathway to rural transformation in Nigeria. *Journal of Agricultural Extension and Rural Development, 14*(2), 78–89.

[30] Ojo, M. A., Mohammed, U. S., & Ibrahim, A. H. (2020). Socioeconomic determinants of rice production in Abuja and Niger State, Nigeria. *International Journal of Agricultural Science and Technology, 8*(1), 43–52.

[31] Okunola, A. M., Adeniran, L. O., & Ojo, F. A. (2020). Impact of rice output and income on food security among farming households in North Central Nigeria. *International Journal of Food Security and Nutrition, 8*(3), 120–132.

[32] Olaitan, M. A., Oyediji, B. I., Bamidele, J., Joel, O. J., Raymond, T., Joel, A. F. & Sennuga, S. O. (2025): The Role of Artificial Intelligence in Promoting Climate-Smart Agriculture through Extension Services in Kaduna State, Nigeria State, *Curr Tren Agron & Agric Res* 1(1): 1-15.

[33] Olaitan, M.A., Oyediji, B. I., Oyotomhe, O.I,, Bamidele, J, Saba, R.M. & Sennuga, S.O. (2025). Community-Based Natural Resource Management as a Catalyst for Sustainable Rural Development: A Critical *Scholastic Agriculture* 1 (3): 01-09.

[34] Olawumi, A. O., Bako, H., Bamidele, J., Oyediji, B. I., Olaitan, M. A., Ibrahim, R. K. & Sennuga, S. O. (2025a). Impact of Gender Inclusion Policies on Women's Participation in Science and Technology in Abuja, Nigeria. *Indiana Journal of Humanities & Social Sciences,* 6(6), 17-28

[35] Olawumi, A. O., Bamidele, J., Olaitan, M. A., Joel, F. J., Eleke, U. P. & Sennuga, S. O. (2025b). Exploring the adoption and use of ICTs for market information access among smallholder soybean farmers in Kuje Area Council, Abuja, Nigeria, *ISRG Journal of Agriculture and Veterinary Sciences (ISRGJAVS)*, 5(2), 32-39

[36] Olawumi, A. O., Oyediji, B. I., Bamidele, J., Eleke, U. P., Olaitan, M. A. & Sennuga, S. O. (2025c). Artificial Intelligence in Agricultural Extension for Sustainable Livelihoods among Rural Farmers in Abuja, Nigeria, *Global Academic Journal of Agriculture and Bio sciences* 7(3): 47-57.

[37] Olayemi, J. K., Amaza, P. S., & Umeh, J. C. (2020). Credit access and household welfare among smallholder farmers in Nigeria. *African Journal of Agricultural Economics and Rural Development, 9*(1), 55–70.

[38] Oyediji, B. I., Olaitan, M. A., Bako, H., Bamidele, J., Ibrahim, R. K. & Sennuga, S. O. (2025). Artificial Intelligence and Agricultural Risk Management for Smallholder Cowpea Farmers and Processors in Niger State, Nigeria. *International Journal of Environmental and Agriculture Research,* 11(7):153-166

[39] Oyediji, B. I., Olawumi, A. O., Bamidele, J., Olaitan, M. A., Eleke, U. P. & Sennuga, S. O. (2025). Impact of Climate Change on Agricultural Productivity and Food Security among Rice Farmers in Oyo State, Nigeria, *International Journal of Agricultural Extension and Social Development,* 8 (6); 130-138

[40] Oyotomhe, O.I., Olawumi, A.O., Bamidele, J., Olaitan, M.A., Oyediji, B. I. & Sennuga, S.O. (2025). Assessing the Adoption of Biotechnology for Sustainable Crop Production among Smallholder Cowpea Farmers in Abuja. *Scholastic Agriculture* 1 (3): 01-09.

[41] Samuelson, P. A., & Nordhaus, W. D. (2010). *Economics* (19th ed.). McGraw-Hill Education.

[42] Usman, A. O., Etuah, M. A., & Yusuf, I. (2021). Empirical analysis of factors influencing household food security among rice farmers in Nigeria. *Journal of Agricultural Economics and Extension, 14*(3), 99–116.

[43] Yusuf, A. O., Ojo, F. A., & Ogunleye, A. S. (2022). Effects of mechanization and irrigation on rice productivity in Sub-Saharan Africa. *African Journal of Agricultural Research, 18*(4), 186–200.

# Comparative Quality of Broiler Manure based Compost with or without Compost Additive and its Effect on the Germination of Pechay

Maanne Ayessa M.Tamayo[1]; Antonio J. Barroga[2*]; Lea S. Caguiat[3]; Justin V. Dumale[4]; Redel L. Gutierrez[5]

[1,3,4,5]Department of Environmental Science and Meteorology, College of Science, Central Luzon State University, Science City of Munoz, Nueva Ecija, Philippines
[*2]Department of Animal Science, College of Science, Central Luzon State University, Science City of Munoz, Nueva Ecija, Philippines
*Corresponding Author

Received:- 08 October 2025/ Revised:- 17 October 2025/ Accepted:- 23 October 2025/ Published: 31-10-2025
Copyright @ 2025 International Journal of Environmental and Agriculture Research
This is an Open-Access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (https://creativecommons.org/licenses/by-nc/4.0) which permits unrestricted Non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

***Abstract—*** *Utilizing broiler manure for composting at the same time addressing environmental issues can be a feasible alternative for broiler raisers. The study aimed to determine the effects of adding a rapid odor erasing and composting microbes (OECM) at different inclusion rates of 350 grams per 100 kg raw material (50 kg broiler manure + 50 kg fly ash), T2 400 grams per 100 kg raw material (50 kg broiler manure + 50 kg fly ash), T3 and 450 grams per 100 kg or raw material (50 kg broiler manure + 50 kg fly ash), T4 on physical properties, temperature, pH, germination rate, and percentage compost recovery. The control T1 was 100 kg raw material with no OECM. A Completely Random Design (CRD) was used consisting of 4 treatments with each treatment replicated thrice. Tukey HSD was used to further analyze significant differences.*

*Result showed that the odor of treated compost was no longer evident on day 13 for T2, T3, and T4. The texture from coarse to fine was observed in day 13 of T2, T3, and T4, while the color from black to grayish black was demonstrated on day 13 of T2, T3, and T4.*

*The temperature ($p. < 0.01$), pH ($p. < 0.01$), compost recovery ($p. < 0.01$), and germination rate ($p. < 0.01$) were significantly different over the control. Therefore, the OECM at 350 grams, 400 grams, and 450 grams per 100 kg raw material is an indispensable additive for broiler-based manure as it significantly improved the varying compost quality parameters.*

***Keywords— Broiler manure composting, poultry waste management, OECM, organic fertilizer, fly ash, odor control, compost quality, germination rate, pH, temperature, compost recovery, sustainable farming.***

## I. INTRODUCTION

According to Bolan et al. (2010), one of the biggest and quickest expanding agricultural sectors in the Philippines and in other country was the poultry industry. Due to its acceptability by most societal segments and its comparatively low cholesterol level, chicken meat was in higher demand. Globally, poultries are one of the Philippines' most significant agricultural subsectors. Among all the animals reared for commercial use, chickens accounted for most of the poultry production in the country.

To date, the Philippines' Central Luzon region has the greatest number of backyard and commercial farms. However, several environmental issues are now facing the chicken sector. This was attributed to the buildup of numerous wastes, particularly manure and litter. If management techniques that are both ecologically and economically viable are not used, the accumulation of these wastes may cause environmental degradation.

Improper waste management has a detrimental effect on the ecology (Maheshwari, 2013). Near chicken farms, land degradation, and nuisances including stink, insects, and rodents are common neighborhood drawbacks. Poor manure management frequently results in the contamination of water and soil containing pathogens, heavy metals, and nutrients in areas where manure was stored. Poultry services emit unpleasant smells and draw rodents, flies, and other pests that spread

disease and annoy the neighborhood. Numerous substances, such as ammonia (NH3), volatile organic compounds (VOCs), and hydrogen sulfide (H2S), can contribute to odor emissions. Consequently, the lives of those who live close to poultry houses are impacted by poultry farms. (Maheshwari, 2013).

Broiler manure was the excess of chicken from poultry industry that can be recycled as nutrient source as it contains the macro nutrients namely: nitrogen, phosphate, and potassium, which can be applied to crops and pasturelands. In Nueva Ecija chicken manure was proven to be efficient as source of organic fertilizer among farmers for their crops (Villegas, 2017).

Moreover, organic fertilizer was a type of fertilizer in which all the components are organic. Because of its composition, it was also safer than synthetic fertilizers. Organic fertilizer can make your plant vibrant, larger, and more nutritious. An organic fertilizer composition includes the manure of chicken, hog, goat, and quail manure, dried leaves, mulching, and other bulking agents. Organic fertilizer was also less expensive than chemical fertilizers, which was why most farmers apply it for their crops and minimizing the use of chemical-based farming.

According to Wardynski (2015), for livestock and poultry farmers, composting has become a more popular strategy for managing animal waste in recent years. Animal dung has been applied as a soil supplement to enhance soil health for a very long time. Application of animal manure compost has several advantages namely: enhanced storage possibilities, reduction in the amount of material that must be carried and distributed on fields, and a better match for hay and pastures throughout the growth period than raw waste.

The researcher was interested in this investigation since organic fertilizer is more chemical-free, inexpensive, and prevent the adverse effects of occupational hazards to farmers. Recently, there was now a growing awareness on the consumption of chemically tainted unhealthy food to our health. The shift to the use of organic fertilizer should be encouraged and maximized. Novel strategies then on how to process animal wastes particularly broiler manure efficiently and rapidly should be explored as it was demand would be expected soon.

### 1.1 Significance of the Study:

Considering the increasing acidity of the soil in recent years, the need to popularize the use of organic fertilizer must be explored to address environmental degradation and mitigate the adverse effect of climate change. Moreover, biomass by-products such as fly ash, which is abundant in Nueva Ecija, should be utilized for maximum productive use, particularly as a bulking agent to produce organic fertilizer. Moreover, out of 65.22M broiler in the Philippines with an average of monthly intake of 195,660,000 million this will produced 48,915,00 kilogram of manure monthly. If this will be now converted for organic production and equal amount of bulking agent will be added there will be a total of 97,830,000 of compost that will be produced. If percentage weight loss in broiler manure-based composting 0.35%, therefore a total of 34,240,500 of organic fertilizer monthly is expected or 684,810 bags of organic fertilizers at 50kg per bag can be produced. This is a potential source of macronutrients supply (NPK) for paddy field rice in the Philippines.

### 1.2 Scope and Limitation of the Study:

The annual based manure is limited to broiler manure only. The different Odor Erasing Microbial Compost additives were 350, 400, and 450 grams per 100 kg raw materials composed of 50 kg broiler manure and 50 kg fly ash. Moreover, different of varying parameters was done from day 1 to 14 days only. The physical parameters of the compost were limited to texture, color, and odor. While the compost quality was measure by compost recover and the germination rate of pechay seeds.

## II. LITERATURE REVIEW

### 2.1 Poultry Manure and its Nutrients:

According to Shaji et al., (2021), chicken manure was a wealthy basis of supplements like nitrogen and phosphorus with contaminants such as antibiotics, hormones, heavy metals, and pathogens. It also increases the fertility of the soil, root development, strength of the plants and their resistant to damages from diseases and pest. However, the negative effects on the utilization of poultry manure can be offset if they are not applied to the soil during warm season due to mineralization (Dikinya & Mufwanzala, 2010).

Animals increased in comprehensive structure ingest a substantial quantity of nitrogenous matter and other materials in their diet. Since between 50% and 80% of the nitrate in food was excreted, turning dietary nitrogen into animal products was inefficient (Arogo et al., 2001). According to Campagnolo et al., (2002), antimicrobic residues were discovered to assess the

prevalence of antimicrobial substances close to large-scale poultry farms in both surface and groundwater resources in Ohio, 12 water samples (67%) were taken.

### 2.2 Waste Management of Broiler Manure:

The main issue with raising poultry was the waste, which needs to be properly treated or it might be dangerous for both the environment and people. Manure was a common term for animal feces and urine; it includes organic material and nutrients that enhance its fertilizer value. Bedding materials, feces, unused feed, and feathers make up the waste byproduct of the chicken business known as litter (Barthod et al., 2018).

Fleming and Freedman (2003), claim that improper disposal of poultry carcasses might cause issues with water quality, particularly in locations that are prone to floods or where the water table was shallow. The following techniques can be used to dispose of poultry carcasses, namely: incineration, composting, and body disposal are all options. Large numbers of sick birds were slaughtered in recent incidents of highly pathogenic avian influenza (HPAI) has created new and difficult issues related to environmental pollution. The likelihood of environmental contamination was increased when there are large quantities of corpses since they can produce enormous quantities of urine and other pollutants.

### 2.3 The Impact of Chicken Manure in Environment:

Chang (2007) it was discovered that the Philippine chicken sector had also encountered constant growth since the introduction of advanced technology in the mid-1950s, as well as the demand viewpoint for the nation's chicken meat and dairy industry would seem favorable considering the country's economic relatively low per capita consuming and estimated economic growth and population growth. In addition, the countries poultry business was dealing with rising consumer demands for product quality, and food safety, as well as public worries about animal protection and the effects of industrialized chicken production on the environment, are all present.

Nevertheless, overusing these organic fertilizers results in environmental pollution like failing air efficiency, enhanced greenhouse gas (GHG) emissions, and abundance of dangerous chemical contaminants. Moreover, nutrient enrichment in water bodies, soil contamination, and improved nutritional loss, especially phosphorus and nitrogen can also be expected. Soil leaching, destruction, and surface runoff stimulated by disregard for agricultural nutrient needs are still prevailing issues (Ru et al., 2018). Improper chicken manure releases an unpleasant stench that attracts flies, pests, and rats, which leads to the spread of infections and antibiotic resistance, as well as being an obvious hazard to people's health (Duan et al., 2019). Therefore, processing and using poultry manure in a sustainable and cost-effective way should be an alternative priority.

### 2.4 Efficient Composting and Strategies:

Composting was a process that quickens the breakdown of manure by utilizing microorganisms like Trichoderma species and other aerobic bacteria and fungi. The so-called Natural Recycling method involves composting. Microorganisms break down poultry dung, which invertebrates then eat. The nutrients, often known as "the compost," are added back to the soil to help plants thrive. The soil's health and water-holding capacity are both improved by compost. (Adugna, 2016). Animal manure management are ways to improve environmental conditions for both animals and humans.

Moreover, composting was the practice of mixing manure with certain other organic materials and fillers to promote aerobic microbial degradation and stabilize biological material while accelerating progress at ideal higher temperatures. Therefore, a product should be available that has unchanging, pathogen-free, and appropriate for use on (Akdeniz, 2019). A compost contains more vitamins and contains organisms that encourages plant development; adding compost to the soil increases its organic material content, soil composition, and farming practices (Manogaran et al., 2017).

### 2.5 Bulking Agent and its Importance in Composting:

The use of bulking agents like “fly ash”, could potentially raise pH levels during composting (Wang et al., 2016). Thus, critical composting technology should be done particularly on the quantity of bulking agent to be incorporated and the regularity of turning the compost pile (Morales et al., 2016).

Moreover, bulking agents help maintain moisture levels and carbon to nitrogen percentage. Air supply control can similarly be the rule of a bulking agent. Finally, wood chips, sawdust, grass hay, wheat bran, corn stalks, grass cuttings, animal manure,

fruit and vegetable waste, garden waste, deciduous leaves, and other materials are some examples of the various bulking agents used in composting (Batham et al., 2018).

### 2.6 Sources and Compositions of Fly ash:

"Fly ash" has already been evaluated both chemically and physically when combined with other substances added to industrial substrates, and it was discovered to offer more flexibility to the finished substrate, enhancing the quality of crops (Castoldi et al., 2014). According to Gupta (2012), "fly ash" serves as one of the bulking agents used in compost, and when it was mixed with other organic supplements such as mud press, organic compost, cow and animal manure, wastewater, and agricultural residues, it can enhance nutritional value of soil vulnerable to deterioration.

Additionally, "fly ash" is regarded as a global environmental risk because it typically includes organic contaminants and potentially harmful metals, including Pb, Se, B, Cr, V, As, Al, and Hg, as well as radioactive elements like uranium and thorium. Furthermore, Philrice in Region III assembled a 6.5 hp water pump modified from UC Davis and NEDO models from Japan. The water pump is powered by biomass and can run continuously for 1.35 hours at a mean pump output of 7.5 lps to a waterway depth of 1.3 meters deep (Juliano et al., 2016).

In Central Luzon, being the rice granary of the Philippines has been disposing a vast quantity of "fly ash" which is the by-product Rice Hull Gasifier Plant. These plants are I. Power Gasifier Plant in San Jose City and GIFT Gasifier Plant in Bacal II Talavera City. According to Reurasia (2016), the I. Power Gasifier Plant is loading 360 tons of rice hull daily to produce 12 Megawatts of electricity while the Talavera Plant is Producing 12 Megawatts out of an input of 480 tons of rice hull daily and a daily disposal of 16 tons of "fly ash". Therefore, the maximum utilization of "fly ash" should be explored.

### 2.7 Qualities of an Ideal Compost:

Composting is a crucial component of the natural greenhouse's production chain. Although the complexity of organic greenhouse production might vary, it is often a system that has significant levels of organic material cycle, large supplies of energy and nutrients, and large production rates (Wurff, 2016).

According to Stehouwer et al., (2022), a broad variety of parameters, including air flow rate, pH, temperature, carbon/nitrogen (C/N) ratio, moisture content, enzyme activity, bulk density, respiration, water holding capacity, microbial colony, porosity, and bioactivity, must be met for compost to be of high quality. These parameters also need to ensure optimal chemical and physical properties in addition to the efficacy of stabilization and maturity. To regulate the procedure "in situ" and make informed judgments regarding its performance, the physical and chemical characteristics of excess must be understood and the variables that affect how well it performs during composting.

Another advantage is the effect that high-quality composting may have on the condition of the soil. When applied to the soil, the addition of compost can supply and restore the soil integrity and structure (Cerda et al., 2018).

### 2.8 Role of Humidity in Influencing Compost Quality:

According to Richard et al., (2002), one significant environmental component that has an impact on many parts of the composting process is moisture. Moisture has an impact on the kinetics of biodegradation by altering the rates of microbial growth, oxygen transport, and water potential and activity.

Composting's dynamic character, which entails variations in particulate size and composition over time, contributes to the intricacy of these molecules. These correlations have been established using a logical theory of the impacts of moisture on composting processes based on basic biological mechanisms and physical properties. Haug (1993), recommended preserving the moisture content of the compost pile between 40% and 60%. Low (below 40%) moisture content limits microbial activity.

### 2.9 Advances in Composting Technology:

The originally primitive composting technique has undergone constant iteration and improvement because of rising demand for intensive livestock farms and growing environmental consciousness among the general population. However, the effect of the energy input and composting facilities on eco-efficiency is minimal (Zhou et al., 2022). According to Jim (2016), there are three commonly used composting techniques: aerobic composting, which uses air to hasten the decomposition of materials; anaerobic composting, which is the reverse of aerobic composting and requires relatively little effort; and vermicomposting, which uses oxygen, worms, and moisture to safely and odorlessly break down biological matter.

Moreover, the miracle catalyst known as the Bio Plus Activator (BPA) contains beneficial microorganisms (BM) that have been cultivated to be extremely active so they can carry out each of their specific activities as effectively as they were designed to. They have not been genetically altered or artificially created; they have been isolated from natural sources. They are kept in a genetically designed food foundation that contains trace minerals, amino and organic acids, enzymes, growth-promoting chemicals, and organic-based substances such as chelating, coagulating, emulsifying, stabilizing, and surface-active agents. The result of more than 40 years of research and development, Beneficial Microbes (BM) includes a variety of naturally occurring microorganisms. With the help of our technology, these Beneficial Microbes collaborate effectively. Beneficial microbes are extremely active and proliferate rapidly under the correct conditions. Beneficial microbes create enzymes to speed up the decomposition of organic materials, which is why they are often referred to as "Super Decomposers." This distinctive quality of BM may be used in a variety of sectors to provide cost-effective solutions that are also environmentally beneficial (Ruiz, 2018).

### 2.10 Features of Rapid Composting Microbes:

According to Raza (2016), composting is a significant and cost-effective way of reusing organic material. The process of generating "developed compost" is ongoing. The study conducted by Kim et al., (2007), found that compost contained a substantial number of heterotrophs and bacterial nitrogen fixers after 90 days of composting utilizing a microbial concoction treatment of sawdust and manure. They documented that a compost additive can influenced enzyme and microbial activity in compost pile aside from hastening its maturity. This suggests that the additive used in a compost pile significantly affected the enzyme reactions of the composting microorganisms, resulting in a considerably quicker breakdown process.

Moreover, in the study of Kim et al., (2005), examine the result of *Synechocystis sp.* on the Chinese cabbage germination index, KACC 91007 is used when there is pig manure or liquid fertilizer for pigs. The initial test entailed the screening of inoculant levels that were, 0.05%, 0.1%, 0.2% and 0.3% correspondingly. Low phytotoxicity and a high Germination index resulted to the choice of 0.05% as the inoculant amount. The results demonstrated that aerobic processing of Pig Liquid Fertilizer for 107 days was superior to anoxic processing and produced more T-N, a macronutrient fertilizer material. Therefore, under aerobic processing conditions, the addition of 0.05% microbial inoculant caused the Chinese cabbage's Germination Index to increase.

Meanwhile, the application of *Trichoderma spp.* to composting is a common strategy for controlling many plant diseases. The biocontrol activities among these species are mostly due to a mixture of different modes of action that may impact the microbiota engaged in compost suppression (Blaya et al., 2013). As a result, Thaha et al., (2020), discovered that utilizing Trichoderma species while composting for 28 days can raise the pH of bio-compost as well as the amounts of potassium, nitrogen, calcium, phosphorus, and C-organics.

According to DA Communication (2022), Dr. Mercedes Garcia of UPLB-Biotech established a microbial-based Bio N biofertilizer to assist Filipino farmers in increasing crop production, such as maize and rice, while preserving soil quality. *Azospirillum*, a nitrogen-fixing bacterium found in soil and charcoal, is present in Bio N. It gives strength to the root structure of a plant, enhances nutritional uptake, offers immunity to pests and diseases, and enhances soil conditions. Finally, applying Bio-N microbial fertilizer is not only increases crop productivity and quality but may also cut rice and corn production costs, which farmers usually agree on.

Furthermore, an Isabela farmer-businessman who has used Bio N for a year, describes the advantages of this unique microbe-based approach. According to Mabunga (2022) believes in using Bio N microbial fertilizer because it helped him produce an additional PHP 15,000.00 per hectares than he previously did with synthetic fertilizers. Also, he experiences with Bio-N has shown amazing outcomes for his rice harvests since he began using it a decade ago. He was able to make savings since these fertilizers are less expensive than those that are currently highly priced on the market. He has been urging his fellow farmers to utilize it since it will benefit us in some manner (Agapito & Mercado, 2022).

## III. METHODOLOGY

### 3.1 Broiler Manure Collection:

The broiler manure was collected from Three J Poultry Farm at Barangay Mangandingay Science City of Muñoz, Nueva Ecija. The broiler manure was collected using the truck of ELR family trading Company and it was delivered directly to ELR family trading Co., Inc. at Barangay Bagong Sikat Science City of Muñoz, Nueva Ecija when the conducting begins, using their truck carrying broiler manure.

**FIGURE 1. Broiler Manure Collection trace map**

### 3.2 The Composition and Preparation Process of the Odor Erasing Composting Microbes (OECM):

The OECM is organic based and was prepared as a concoction using the following: 7 bacteria for decomposition, enzyme production, and nutrients transformation; 3 bacteria for decomposition of polysaccharides and enzyme production; 3 bacteria for enhance decomposition, compost "sweetening" and probiotics; 5 bacteria for nitrogen fixation and nutrients transformation; 7 fungi for decomposition, probiotics production and nutrients transformation.

The preparation process involved the following: Classification of the substrate materials based on the modified growth media; comminution or griding of the substrate materials; mixing and blending of substrate materials for homogeneity; nutrient fortification of the substrate to enhance the growth of the super stain beneficial microbes; sterilization; inoculation and subsequent incubation of the beneficial microbes; and propagation and subsequent multiplication of the beneficial microbes in the prepared substrate.

The source of substrate were haystack and decaying woods, cattle manure and silage, dairy processing plant sewerage, fermented vegetables fruits, pineapple pulp, stale bread, waste lagoons, garbage landfills, biogas digester, soil in organic fertilizer plants, oxidation of sewage plants, decomposed sugar cane and waste mushroom substrate and waste effluent.

### 3.3 Compost Plot Preparation:

Twelve plots measuring 4 ft. x 4 ft. x 1 ft., representing 4 treatments, were replicated three times. Temperature, pH, and moisture were taken from three sampling sites (top, middle, and bottom of the treated plots). Replicates of samples from these treated plots were analyzed for temperature, pH, and moisture by a 4-in-1 soil survey instrument, while the odor, color, and texture were physically observed and recorded.

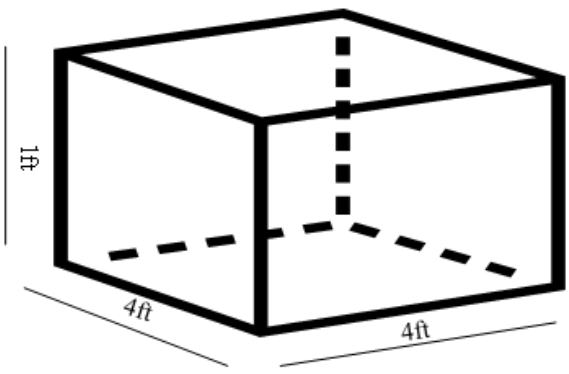



**FIGURE 2: Compost Plot Diagram**

### 3.4 Treatment Assignments:

**TABLE 1**
**TREATMENTS AND COMPOSITION OF COMPOST IN THIS STUDY**

| Treatment | Composition |
|---|---|
| Treatment 1 (control) | 50 kg Broiler Manure + 50 kg Fly Ash |
| Treatment 2 | 50 kg Broiler Manure + 50 kg Fly Ash + 350 grams OECM |
| Treatment 3 | 50 kg Broiler Manure + 50 kg Fly Ash + 400 grams OECM |
| Treatment 4 | 50 kg Broiler Manure + 50 kg Fly Ash + 450 grams OECM |

### 3.5 Treatment Plots Management:

All the experimental treatment plots were stirred vigorously, and it was done at 6:00 AM; 2:00 PM and 10:00 PM from Day 1 to Day 7 and 6:00 AM; 6:00 PM from Day 8 to Day 14. The following compost parameters was recorded immediately after every stirring session.

### 3.6 Data Gathered:

To address production performance and improvements, the following data was collected in order.

1) (%) Weight Loss- the final weight was measured minus the original weight of the compost material divided by the original weight x 100. Harvest recovery was collected to know how much weight was left and how much was reduced after the composting process. The final weight of the compost was weighed using a 100kg dial table scale.
2) Temperature, pH, and Moisture – was measured by 3 in 1 portable soil test kit and was taken from three sampling sites (top, middle and bottom of the treated plots) from 6am, 2pm, and 10pm from day 1 to day 7 and 6am, and 6pm from day 8 – day 14. Before placing again 3 in 1 portable soil test kit to compost pile, the gadget was cleaned by tissue temperature or the pH gathered in the previous files monitored, minimizing the measurements biased during data gathering.
3) NPK - was analyzed in Soils Laboratory in San Fernando Pampanga
4) Texture, color, and odor – was physically observed in every treatment replicates
5) Germination rate, (%) - was computed by counting the number of seeds germinated divided by the total number of seeds sown multiplied by 100%. Counting the number of pechay seed that grew in each treatment replicates after 7 days was important to consider which treatment stood out using all treatment replicates in the growth of pechay seed.

### 3.7 Germination of Pechay Seed:

The 100 pieces of pechay seeds was sown directly to the treated compost piles, maintain the moisture of the soil until the sprouts appear and counting for germination was start at the moment of a pechay seed sprout. In just 3-4 days, you can see small buds starting to emerge from the soil. Counting terminates after 7 days only.

### 3.8 Statistical Analysis:

All analyses were performed using RStudio version 4.3.0. One-way Analysis of Variance (ANOVA) was used to test the difference among treatment means and a p-value less than the level of significance (0.05) indicates that there is at least one treatment mean is different. Tukey's HSD test as a post-hoc test was used to test the pairwise comparison among treatment means.

## IV. RESULT AND DISCUSSION

### 4.1 Comparative Temperature compost with or without OECM:

(Table 2a-b) shows the 14 days temperature mean values gathered during composting period from T1 (50 kg broiler manure + 50 kg fly ash), T2 (50 kg broiler manure + 50 kg fly ash + 350 grams OECM), T3 (50 kg broiler manure + 50 kg fly ash + 400 grams OECM), and T4 (50 kg broiler manure + 50 kg fly ash + 450 grams OECM).

**TABLE 2a**

**COMPARATIVE TEMPERATURE OF BROILER BASED MANURE COMPOST WITH OR WITHOUT OECM**

| Treatment | Day 1 | Day 2 | Day 3 | Day 4 | Day 5 | Day 6 | Day 7 |
|---|---|---|---|---|---|---|---|
| T1 | $39.67^{c}$ | $49.00^{c}$ | $47.78^{d}$ | $48.00^{d}$ | $47.00^{d}$ | $41.56^{d}$ | $41.00^{c}$ |
| T2 | $41.44^{a}$ | $57.33^{a}$ | $55.89^{a}$ | $55.11^{a}$ | $55.56^{a}$ | $55.67^{a}$ | $51.67^{a}$ |
| T3 | $38.22^{d}$ | $49.56^{c}$ | $51.33^{c}$ | $49.89^{c}$ | $48.67^{c}$ | $48.56^{c}$ | $47.11^{b}$ |
| T 4 | $40.44^{b}$ | $52.67^{b}$ | $54.56^{b}$ | $53.56^{b}$ | $52.11^{b}$ | $49.89^{b}$ | $48.11^{b}$ |
| p-value | <0.001* | <0.001* | <0.001* | <0.001* | <0.001* | <0.001* | <0.001* |

**TABLE 2b**

**COMPARATIVE TEMPERATURE OF BROILER BASED MANURE COMPOST WITH OR WITHOUT OECM**

| Treatment | Day 8 | Day 9 | Day 10 | Day 11 | Day 12 | Day 13 | Day 14 |
|---|---|---|---|---|---|---|---|
| T1 | $38.67^{d}$ | $37.50^{d}$ | $35.17^{d}$ | $34.67^{d}$ | $34.33^{d}$ | $33.67^{c}$ | $32.67^{a}$ |
| T2 | $48.00^{a}$ | $47.50^{a}$ | $45.17^{a}$ | $44.00^{a}$ | $39.50^{a}$ | $36.67^{a}$ | $32.33^{a}$ |
| T3 | $44.50^{b}$ | $42.17^{b}$ | $40.00^{b}$ | $39.00^{b}$ | $36.50^{b}$ | $35.00^{b}$ | $31.67^{a}$ |
| T4 | $41.00^{c}$ | $39.00^{c}$ | $38.00^{c}$ | $37.17^{c}$ | $35.50^{c}$ | $33.33^{c}$ | $31.67^{a}$ |
| p-value | <0.001* | <0.001* | <0.001* | <0.001* | <0.001* | <0.001* | 0.16 |

***Significant at 5% level***

The temperature measurements and assessed mean values from day 1 to day 7 are summarized in (table 2a) to highlight the 7-day temperature trends of different compost treatments and in (table 2b) is the assessed values from day 8 to day 14 of composting in the study. The data results showed that their significant difference between T2, T3, and T4, whereas T1 was significantly different from T2, T3, and T4. Moreover, temperatures in compost piles range from 38.22 to 41.44 °C at the initial phase of composting. The mean temperature recorded after 14 days of composting ranged from a minimum of 39.67 °C for T1 (50 kg broiler manure + 50 kg fly ash) to a maximum temperature of 49 °C. For T2 (50 kg broiler manure + 50 kg fly ash + 350 grams OECM), 41.44°C to 57.33 °C; for T3 (50 kg broiler manure + 60 kg fly ash + 400 grams OECM), 38.22 to 51.33 °C and T4 (50 kg broiler manure + 50 kg fly ash + 450 grams OECM), 40.55 to 54.56 °C. (Table 2a-b).

Meanwhile, the data showed that, from Day 8 to Day 14 (table 2b) the temperature starts to drop, the maximum temperature ranged, can be seen on Day 8 to Day 14 the maximum ranged was 48°C and the minimum ranged was 31°C. Temperatures in compost piles means range from 39°C to 57°C at the initial phase of composting. All experimentally treated piles were able to reach the three temperature phases necessary for efficient sanitization during the composting duration (CCME 2005; Eusufzai et al., 2013) of the feedstock and process efficiency: the mesophilic phase, where temperatures are between 15°C and 45 °C; the thermophilic phase, with temperatures between 45°C and 70°C; and the cooling phase, when the pile temperatures drop below 60 °C.

Hence, aeration is the primary purpose for turning the compost three times each day from day 1 to day 7. Microbes are responsible for decomposition, and to survive and perform their necessary functions, these microbes must be able to breathe. These microorganisms disappear in the absence of oxygen, which slows down degradation. It must be turned whenever the temperature falls below 40°C to maintain a thermophilic pile before harvesting,

Further, a biological and metabolic process called composting includes bacteria and the enzymes they release (Zeng et al., 2010). Changes in composting temperature indicate changes in microorganisms in the compost substrate and increases in compost substrate temperature are due to metabolic heat accumulation of microorganisms in the compost substrate, indicating the metabolic intensity and conversion rate of organic matter. What is important for microbes in the matrix (Wang et al., 2011).

One of the key factors used to assess the composting process is temperature because it affects both the frequency at which multiple biological reactions occur and how sanitary the outcome is (Bustamante et al., 2008).

### 4.2 Comparative pH of compost with or without OECM:

(Table 3a-b) shows the 14 days pH mean values gathered during the 14 days composting from T1 (50 kg chicken manure + 50 kg fly ash), T2 (50 kg chicken manure + 50 kg fly ash + 350 grams OECM), T3 (50 kg CM + 50 kg fly ash + 400 grams OECM), and T4 (50 kg CM + 50 kg fly ash + 450 grams OECM).

**TABLE 3a**

**COMPARATIVE PH OF BROILER BASED MANURE COMPOST WITH OR WITHOUT OECM**

| Treatment | Day 1 | Day 2 | Day 3 | Day 4 | Day 5 | Day 6 | Day 7 |
|---|---|---|---|---|---|---|---|
| T1 | $5.80^{b}$ | $5.69^{b}$ | $5.33^{b}$ | $5.46^{a}$ | $5.37^{ab}$ | $5.46^{a}$ | $5.54^{a}$ |
| T2 | $6.21^{a}$ | $6.03^{a}$ | $5.71^{a}$ | $5.50^{a}$ | $5.57^{a}$ | $5.54^{a}$ | $5.44^{a}$ |
| T3 | $6.09^{a}$ | $5.86^{ab}$ | $5.22^{b}$ | $5.36^{a}$ | $5.27^{ab}$ | $5.50^{a}$ | $5.57^{a}$ |
| T4 | $5.79^{b}$ | $5.92^{ab}$ | $5.22^{b}$ | $5.48^{a}$ | $5.24^{b}$ | 5.4 | $5.38^{a}$ |
| p-value | <0.001* | 0.014* | <0.001* | 0.1 | 0.035* | 0.656 | 0.33 |

***Significant at 5% level***

**TABLE 3b**

**COMPARATIVE PH OF BROILER BASED MANURE COMPOST WITH OR WITHOUT OECM**

| Treatment | Day 8 | Day 9 | Day 10 | Day 11 | Day 12 | Day 13 | Day 14 |
|---|---|---|---|---|---|---|---|
| T1 | $5.25^{a}$ | $5.30^{a}$ | $5.63^{a}$ | $5.57^{a}$ | $5.48^{a}$ | $5.60^{a}$ | $5.58^{a}$ |
| T2 | $5.43^{a}$ | $5.62^{a}$ | $5.82^{a}$ | $5.72^{a}$ | $5.62^{a}$ | $5.63^{a}$ | $5.62^{a}$ |
| T3 | $5.22^{a}$ | $5.52^{a}$ | $5.77^{a}$ | $5.77^{a}$ | $5.55^{a}$ | $5.40^{a}$ | $5.62^{a}$ |
| T4 | $5.40^{a}$ | $5.62^{a}$ | $5.78^{a}$ | $5.67^{a}$ | $5.67^{a}$ | $5.55^{a}$ | $5.63^{a}$ |
| p-value | 0.223 | 0.44 | 0.418 | 0.24 | 0.226 | 0.099 | 0.857 |

***Significant at 5% level***

pH of compost piles ranges from 5.79 to 6.21 at the initial phase of composting. The mean pH values recorded after 14 days of composting ranged from 5.2 to 5.8 for T1, 5.4 to 6.2 for T2, 5.2 to 6.0 for T3, and 5.2 to 5.9 for T4. During 14 days of composting, the mean pH values recorded on T2, T3, and T4 were not significantly different, whereas T1 was significantly different to T2, T3, and T4.

Moreover, the final pH value gathered from different compost piles was 5.58 for T1, 5.62 for T2, 5.62 for T3, and 5.63 for T4. T2, T3, and T4 pH values are classified as moderately acidic (5.6-6.0) by the United States Department of Agriculture's National Resources Conservation Service, whereas T1 pH value is classified as extremely acidic (5.1-5.5) (Burt, 2014). Beck-Friis et al., (2001) noted that the transition from mesophilic to thermophilic conditions correlated with a change in pH from acidic (pH = 4.5–5.5) to alkaline (pH = 8–9); in addition, all experimental plots in this study reached the thermophilic phase (45–70 °C) (Papale et al., 2021). The constant temperature (39–57°C) throughout composting resulted in stable pH levels ranging from 5.2–6.2 from days 1–14. In accordance with Bunt (1988), the final pH values recorded from all experimental piles (Table 3b) were within the ideal range for growing media, which is between 5.2 and 7.3.

### 4.3 Comparative Physical Properties of compost with or without OECM:

Composting was carried out for 14 days. Table 4a -4d below informs the results of the color, odor, texture, and moisture of the compost during the study. In general, the mature compost has physical characteristics such as Grayish Black color and smells close to the smell of earth. This is because the material it contains already resembles soil material.

**TABLE 4a**

**COMPARATIVE DAILY PHYSICAL PARAMETERS OF BROILER-BASED MANURE WITHOUT OECM**

| Days | Treatment 1 | | |
|---|---|---|---|
| | Texture | Color | Odor |
| 1 | Coarse | Black | Slightly Offensive |
| 2 | Coarse | Black | Slightly Offensive |
| 3 | Coarse | Black | Slightly Offensive |
| 4 | Coarse | Black | Slightly Offensive |
| 5 | Coarse | Black | Slightly Offensive |
| 6 | Coarse | Black | Slightly Offensive |
| 7 | Coarse | Black | Slightly Offensive |
| 8 | Coarse | Black | Slightly Offensive |
| 9 | Coarse | Black | Slightly Offensive |
| 10 | Coarse | Black | Slightly Offensive |
| 11 | Coarse | Black | Slightly Offensive |
| 12 | Coarse | Black | Slightly Offensive |
| 13 | Coarse | Black | Slightly Offensive |
| 14 | Coarse | Black | Slightly Offensive |

Table 4a shows that from day 1 to day 14, the texture of the broiler-based manure compost appeared to be coarse, black in color, and had a slightly odor. There were no changes observed in treatment 1 physical parameters during 14 days of composting.

**TABLE 4b**

**COMPARATIVE DAILY PHYSICAL PARAMETERS OF BROILER-BASED MANURE WITH 350 GRAMS OF OECM**

| Days | Treatment 2 | | |
|---|---|---|---|
| | Texture | Color | Odor |
| 1 | Coarse | Black | Slightly Offensive |
| 2 | Coarse | Black | Slightly Offensive |
| 3 | Coarse | Black | Slightly Offensive |
| 4 | Coarse | Black | Slightly Offensive |
| 5 | Coarse | Black | Slightly Offensive |
| 6 | Coarse | Black | Slightly Offensive |
| 7 | Coarse | Black | Slightly Offensive |
| 8 | Slightly coarse | Black | Slightly Offensive |
| 9 | Slightly coarse | Black | Slightly Offensive |
| 10 | Slightly coarse | Black | Odorless |
| 11 | Slightly coarse | Black | Odorless |
| 12 | Slightly coarse | Black | Odorless |
| 13 | Fine | Grayish Black | Odorless |
| 14 | Fine | Grayish Black | Odorless |

Table 4b shows that from day 1 to day 7, the texture of the broiler-based manure compost appeared to be coarse; on days 8 to 12, it was slightly coarse, then appeared to be fine on days 13 to 14. The color on days 1 to 12 was black and became grayish black on days 13 to 14. Further, the odor of the compost from day 1 to day 9 was slightly offensive, and on day 10 of composting, it became odorless. The result showed that the compost was ready to be used after 14 days of composting.

**TABLE 4c**

**COMPARATIVE DAILY PHYSICAL PARAMETERS OF BROILER-BASED MANURE WITH 400 GRAMS OECM**

| Day | Treatment 3 | | |
|---|---|---|---|
| | Texture | Color | Odor |
| 1 | Coarse | Black | Slightly Offensive |
| 2 | Coarse | Black | Slightly Offensive |
| 3 | Coarse | Black | Slightly Offensive |
| 4 | Coarse | Black | Slightly Offensive |
| 5 | Coarse | Black | Slightly Offensive |
| 6 | Coarse | Black | Slightly Offensive |
| 7 | Coarse | Black | Slightly Offensive |
| 8 | Slightly coarse | Black | Slightly Offensive |
| 9 | Slightly coarse | Black | Slightly Offensive |
| 10 | Slightly coarse | Black | Odorless |
| 11 | Slightly coarse | Black | Odorless |
| 12 | Slightly coarse | Black | Odorless |
| 13 | Fine | Grayish Black | Odorless |
| 14 | Fine | Grayish Black | Odorless |

Table 4c shows that from day 1 to day 7, the texture of the broiler-based manure compost appeared to be coarse; on days 8 to 12, it was slightly coarse, then appeared to be fine on days 13 to 14. The color on days 1 to 12 was black and became grayish black on days 13 to 14. Further, the odor of the compost from day 1 to day 9 was slightly offensive, and on day 10 of composting, it became odorless. The result showed that the compost was ready to be used after 14 days of composting.

**TABLE 4d**

**COMPARATIVE QUALITY PHYSICAL PARAMETERS OF BROILER-BASED MANURE WITH 450 GRAMS OECM**

| Day | Treatment 4 | | |
|---|---|---|---|
| | Texture | Color | Odor |
| 1 | Coarse | Black | Slightly Offensive |
| 2 | Coarse | Black | Slightly Offensive |
| 3 | Coarse | Black | Slightly Offensive |
| 4 | Coarse | Black | Slightly Offensive |
| 5 | Coarse | Black | Slightly Offensive |
| 6 | Coarse | Black | Slightly Offensive |
| 7 | Coarse | Black | Slightly Offensive |
| 8 | Slightly coarse | Black | Slightly Offensive |
| 9 | Slightly coarse | Black | Slightly Offensive |
| 10 | Slightly coarse | Black | Odorless |
| 11 | Slightly coarse | Black | Odorless |
| 12 | Slightly coarse | Black | Odorless |
| 13 | Fine | Grayish Black | Odorless |
| 14 | Fine | Grayish Black | Odorless |

Table 4d shows that from day 1 to day 7, the texture of the broiler-based manure compost appeared to be coarse; on days 8 to 12, it was slightly coarse, then appeared to be fine on days 13 to 14. The color on days 1 to 12 was black and became grayish black on days 13 to 14. Further, the odor of the compost from day 1 to day 9 was slightly offensive, and on day 10 of composting, it became odorless. The result showed that the compost was ready to be used after 14 days of composting.

In general, tables 4a–d showed that there was no significant variation in physical parameters (odor, color, and texture) observed over 14 days of composting between treatments 2, 3, and 4, however T1 was found to be different throughout all the treatments

treated with OECM. The final form of compost does not resemble the original form because it has been destroyed due to natural decomposition by microorganisms that live in the compost. *Thiobacillus thiooxidans* and *Thiobacillus ferrooxidans* microbes eliminated the slightly offensive odor in the piles. Furthermore, as described by Ayunin et al. (2016), characteristics of compost with inclusion rates of 350 grams, 400 grams, and 450 grams of OECM in this study display signs of maturation after only 13 to 14 days of composting, having a grayish black color, no foul odor, and a fine texture (Table 4a–d).

### 4.4 Comparative Weight loss of compost with or without OECM:

Weight Loss is measured to differentiate the influence of compost additive to the mass of different compost treatments used in the study. Higher values in the provided data below means greater weight loss (Table 5).

**TABLE 5**
**COMPARATIVE WEIGHT LOSS OF BROILER BASED MANURE COMPOST, %**

| Treatment | Harvest Recovery |
|---|---|
| Treatment 1 | 28.667[b] |
| Treatment 2 | 39.667[a] |
| Treatment 3 | 32.000[b] |
| Treatment 4 | 36.667[a] |
| p-value | <0.001* |

***Analysis of variance at .05% level of significance***

Data showed that there was significant difference (p-<0.01) between T1 (control), T2, T3, and T4. Based on the result, significant maximum reduction in total weight was observed in treatment 2 (39.67) and the lowest reduction was observed in treatment 1 (28.67). On the basis of fully decomposed broiler manure, fly ash with different inclusion of OECM compost, the carbon content was worked out at 14 days in that observed maximum reduction in total organic carbon content. (Miller & Spoolman (2013) confirmed once more that compost is created when worms, microorganisms, primarily fungi and aerobic bacteria, break down organic waste in the presence of oxygen. Similarly, PCAMRD-DOST (2014) described how fungus and bacteria break down waste so that worms can finish the job and improve decomposition. Hence, all experimentally treated piles in the study lost 10 to 50% of their starting weight, related to the work of Breitenbeck and Schellinger (2013).

In addition, the more compost ingredient put to the pile, the greater the weight loss. (Table 5). The compost pile decreases in size from when it first started to compost, which shows that different bacteria are degrading the compost.

### 4.5 Comparative Germination rate of compost with or without OECM:

The Germination Index is calculated to illustrate which of the experimental treatments will be most effective and to distinguish between compost made from Chicken manure and pechay germination. A higher rate of germination is indicated by higher values for this measurement.

**TABLE 6**
**COMPARATIVE GERMINATION RATE OF PECHAY, %**

| Treatment | Germination |
|---|---|
| Treatment 1 | 36.667[d] |
| Treatment 2 | 87.333[a] |
| Treatment 3 | 76.667[b] |
| Treatment 4 | 61.000[c] |
| p-value | <0.001* |

***Analysis of variance at .05% level of significance***

Data showed that there was significant difference (p-<0.01) between Treatment 1 (control), Treatment 2, Treatment 3, and Treatment 4. T1 (50kg broiler manure and 50 kg fly ash) got the lowest germination rate having (36.667), followed by Treatment 4 (50kg broiler manure, 50kg of fly ash and 450 grams OECM) got (61.000), Treatment 3 (50kg broiler manure, 50kg fly ash and 400 grams OECM) got (76.667), and Treatment 2 (50kg broiler manure, 50kg fly ash and 350 grams OECM) which get the highest germination rate among all the treatments having (87.337). Based on the result, treatment 2 was stood-out between treatment, treatment 3 and treatment 4 because of high germination rate

The study by Kim et al. (2005) shows that adding 0.05% of microbial inoculants enhances the pig liquid fertilizer (PLF) and increases the germination index of Chinese cabbage. The study findings also indicated that aerobic processing of PLF for 107 days was superior to anoxic processing and produced more macronutrient fertilizer material such as nitrogen, potassium, and phosphorus. Furthermore, Sace (2018), the plants cannot adequately absorb nutrients and would exhibit signs of shortages if the pH were too high (alkaline) or too low (acidic). Also, data showed (Table 6) showed that the effectiveness of using compost quality harvested compost as a potting media of pechay seeds in terms of GI. To assess the phytotoxicity and maturity of compost using one of these methods, the seed germination index (GI) has been widely used (Luo et al., 2018). Zucconi et al. (1981), proposed the GI, which includes the effect of phytotoxic substances on seedling germination rate and radicle elongation.

## V. SUMMARY

The environmental impact of poultry production has received increasing attention over the last several decades. Masarirambi et al. (2012) have further stated that chicken manure, would help to decrease the measure of harmful mixture created by ordinary manures. It was stated in their study that chicken manure is perceived as perhaps the best of this organic compost because of its high nitrogen content. In addition, manures supply different supplements and fill in as soil revision. The main objectives of the study were to (a) determine the odor, color, texture, temperature, pH, and moisture of the various compost treatments, (b) determine the harvest recovery of the various compost treatments, and (c) determine the germination index of pechay seeds from the various compost media. To achieve the objectives that were established and carried out from April to May 2023 at Muñoz, Nueva Ecija's Barangay Bagong Sikat Science City.

Compost additives are combinations of fertilizer, bacteria, or fungi that are meant to hasten the composting process. Fly ash has considerable value as a bulking agent in composting organic wastes, it is anticipated to solve the difficulties of industrial waste disposal, and it is expected to solve these problems.

Twelve replications and four treatments are used in the study. Prior to being added to the potting media trays, the chicken manure degraded in just 14 days. The outcomes reveal that T2 87.333 average's GI, which is composed of (50 kg CM, 50 kg fly ash, and 350g BPA), has a significantly significant impact on GI in comparison to the other treatments.

## VI. CONCLUSION

The study has shown that T2 was most effective in reducing the weight of the compost Likewise, it produced the highest percentage on the germination of pechay which 87.333 % among other treatments tested got the lowest rate of germination like in the t1 (control) had a total of 36.67 % only. For economic reason, composting alone may also be a good alternative treatment for vermicompost production. Moreover, the study confirmed on day 14 that all the inclusion levels of the OECM to the broiler manure did not influence increased in temperature. The study confirmed that all the inclusion levels of the OECM to the broiler manure did not influence significant change in pH. The study concluded that the inclusion level of OECM at 350 grams ($p-<0.01$) significantly increased the % weight loss at 39.67% over the control which is only 28.67%

## VII. RECOMMENDATION

The study recommends a higher inclusion level to significantly increased the temperature in future studies because the ideal composting temperature requirements is around 60-65°C for thermophilic microbes. The study recommends a higher inclusion level to significantly increased the pH because is essential to the plants. The study recommends an inclusion level of 350 grams OECM to significantly increase germination index. The study recommends an inclusion level of 350 grams of OECM to significantly increase compost weight loss.

Considering the economics of the utilization of the OECM, a lower inclusion rate can thus be recommended to lower the production cost of the compost. Furthermore, the researcher recommends including the following parameters for future studies: present of heavy metals, porosity, NPK, and C:N ratio.

## REFERENCES

[1] Adugna, G. (2016). A review on impact of compost on soil properties, water use and crop productivity. *Academic Research Journal of Agricultural Science and Research, 4(3), 93-104* doi:10.14662/ARJASR2016.010

[2] Agapito, A. J. I., & Mercado, S. M. (2022), Use Bio N today, keep high farm costs away https://horizon.uplb.edu.ph/uplb-features/use-bio-n-today-keep-high-farm-costs-away/

[3] Arogo, J., Westerman, P. W., Heber, A. J., Robarge, W. P. & Classen, J. J. (2001). *Ammonia in animal production – a review.* Sacramento, USA: American Society of Agricultural and Biological Engineers.

[4] Ayunin, R. W., Nugraha, W. D., Samudra, G., (2016) Jurnal Teknik Lingkungan, 5, 1-10

https://doi.org/10.1051/e3sconf/202233500034

[5] Balcel, M., Dimaunahan, R. S., Mapa, C. & Abuan, D. (2016). pH analyzer device with microcontroller-based water neutralization system for pechay cultivation. LPU-Laguna Journal of Engineering and Computer Studies Vol. 3 No.

[6] Barthod, J. (2018), Composting with additives to improve organic amendments. A review *Agronomy for Sustainable Development volume 38.* doi.org/10.1007/s13593-018-0491-9

[7] Batham, M., Gupta, R., & Tiwari, A. (2018), Implementation-of-bulking-agents-in-com posting *J Bioremed Biodeg 2013, 4:7.* http://dx.doi.org/10.4172/2155-6199.10002

[8] Blaya, J., Mondéjar, R. L., Lloret, E., Pascual, J. A., & Ros, M. (2013), Changes induced by Trichoderma harzianum in suppressive compost controlling Fusarium wilt *Pesticide Biochemistry and Physiology Volume 107, Issue 1* doi.org/10.1016/j.pest bp.2013.06.001

[9] Bolan, N. S., Szogi, A. A., Chuasavathi, T., Seshadri, B., Rothrock Jr. M.J., & Panneerselvam, P. (2010), Uses and management of poultry litter. *World's Poultry Science Journal Volume 66, 2010 - Issue 4* https://doi.org/10.1017/S0043933910000656

[10] Breitenbeck G. & Schellinger D. (2013). Calculating the Reduction in Materials Mass And Volume during Composting. Compost Science & Utilization 12(4):365-371. DOI:10.1080/1065657X.2004.10702206

[11] Bunt, A.C. (1998). Media and Mixes for Container-Grown Plants, *second ed. Unwin Hyman Ltd., London, UK*. DOl 10.1007/978-94-011-7904-1

[12] Burt, R. (2014). Soil Survey Staff: Soil Survey Field and Laboratory Methods Manual-Soil Survey Investigations Report, Vol. 51. Washington, DC: US Department of Agriculture, 227–234.

[13] Campagnolo, E. R., Johnson, K. R., Karpati, A., Rubin, C. S., Kolpin, D. W., Meyer, M. T., Estaben, E., & Mcgeehin, M. (2002). Antimicrobial residues in animal waste and water resources proximal to large-scale swine and poultry feeding operations. Science of the Total Environment, 299, 89–95.

[14] Chang, H. S. C. (2007). Analysis of the Philippine chicken industry: Commercial versus backyard sectors. Asian Journal of Agriculture and Development, 4(1), 41-56.

[15] Cerda, A., Artola, A., Font, X., Barrena, R., Gea, T., & Sánchez, A. (2018), Composting of food wastes: Status and challenges *Bioresource Technology Volume 248* doi.org/10.1016/j.biortech.2017.06.133

[16] DA Communication Group (2022), From Business Mirror: Uplb-Biotech's Bio N may help ease Ph farmers' fertilizer Woes. https://www.da.gov.ph/from-business-mirror-uplb-biotechs-bio-n-may-help-ease-ph-farmers-fertilizer-woes/

[17] Dikinya, O., & Mufwanzala, N. (2010), Chicken manure-enhanced soil fertility and productivity: Effects of application rates *Journal of Soil Science and Environmental Management Vol. 1(3).* http://www. academicjournals.org/JSSEM

[18] Fleming, R., & Freedman R. (2003), Water quality impacts of burying livestock mortalities

https://www.yumpu.com/en/document/read/29364192/on-farm-composting-of-cattle-mortalities-ridgetown-campus-

[19] Haug, R. T. (1993), Process kinetics and product stability *The Practical Handbook of Compost Engineering. Lewis Publishers;* Boca Raton, FL, USA: 1993. pp. 335–383.

[20] Jim (2016), Different Kinds of Composting https://unclejimswormfarm.com/different-kinds-composting/

[21] Juliano, A. S., Gavino, R. B., Agulto, M. E., & Taylan, V. T. (2016), Improvement of PhilRice-Designed Ricehull Gasifier Engine-Pump System for Rainfed Lowland Irrigation *13th International Agricultural Engineering Conference and Exhibition and 66th Annual PSAE Convention* https://www.researchgate.net/publication/ 316921994

[22] Kim, T. I., Yoo, Y. H., Chung, E. S., Barroga, A. J., Yang, C. B., & Kim, M. K. (2005), Effect of Microbial Inoculant to Pig Liquid Fertilizer on Germination Index of Chinese Cabbage *Journal of Animal Environmental Science 11(2)*

https://www.researchgate.net/publication/264113127

[23] Kim, T. I., Song, J. I., Chung, E.S., & Barroga, A. J. (2007), Microbial and enzyme dynamics of compost with additive. *Philippine Agricultural Scientist 90(4):295-304*

https://www.researchgate.net/publication/289836732_Microbial_and_enzy me_dynamics_of_compost_with_additive

[24] Larney, F.J., K.E. Buckley, X. Hao and W.P. McCaughey. 2006. Fresh, stockpiled, and composted beef cattle feedlot manure: nutrient levels and mass balance estimates in Alberta and Manitoba. J. Environ. Qual. 35:1844-1854.

[25] Maheshwari, S. (2013), Environmental impacts of poultry production *Poultry, Fisheries & Wildlife Sciences, 1(1), 1-3.* DOI: 10.4172/pfw.1000101

[26] Manogaran, M. D., Shamsuddina, R., Hizami, M., Yusoff, M., Lay, M., & AliSiyal, A. (2017), A review on treatment processes of chicken manure Cleaner and Circular Bioeconomy Volume 2, 100013. https://doi.org/10.1016/j.clcb.2022.1000 13

[27] Masarirambi, M., Dlamini, P., Wahomi, P., and Oseni, T. (2012). Effects of Chicken Manure on Growth, Yield and Quality of Lettucev (*Lactuca sativa L.)* 'Taina' Under a Lath Housen in a Semi-Arid Sub-Tropical Environment

[28] Miller G. T., Spoolman, S. E., 2013 Environmental science. 14th edition. Brooks/Cole, Cengage Learning, USA, 576 pp.

[29] Philippine Council for Aquatic and Marine Research and Development (PCAMRD- Department of Science and Technology (DOST), 2004 How to produce vermicompost and vermimeal with "vermi" in the backyard. Philippine Council for Aquatic and Marine Research and Development (DOST), Jamboree Road, Timugan, Los Banos, Laguna 4030, Philippines, pp. 3-5.

[30] Papale M, Romano I, Finore I, Lo Giudice A, Piccolo A, Cangemi S, Di Meo V, Nicolaus B, Poli A. Prokaryotic Diversity of the Composting Thermophilic Phase: The Case of Ground Coffee Compost. Microorganisms. 2021 Jan 21;9(2):218. doi: 10.3390/microorganisms9020218. PMID: 33494462; PMCID: PMC7911569.

[31] Raza, S. (2016), Composting process: a review. *International Journal of Biological Research.*

https://doi.org/10.14419/ijbr.v4i2.6354

[32] Reurasia (2016), Nueva Ecija turning into the capital of "green" energy in Philippines. https://reurasia.com/nueva-ecija-turning-into-the-capital-of-green-energy-in-philippines/

[33] Richard, T. L., Hamelers, H. V. M., Veeken, A., & Silva, T. (2002), Moisture relationships in composting processes *Compost Science & Utilization* 10(4):286-302

[34] Ru, S. H., Zhang, G., Niu, J. F., Sun, S. Y., Wang, L. & Geng, N. (2018), Effects of Chicken Manure Application on Crop Yield, International Confe. Biotechnogy Engineering and Biological, 1392-1396. https://ieeexplore.ieee.org/document/6245393

[35] Ruiz, R. L., (2018) Beneficial Microorganism "Super Decomposer" Uncategorized
http://elrfamilytrading.com/2018/12/14/beneficial-microorganism-super-decomposer/

[36] Shaji, H., Chandran, V., & Mathew, L. (2021), Chapter 13 - Organic fertilizers as a route to controlled release of nutrients *Controlled Release Fertilizers for Sustainable Agriculture* doi.org/10.1016/B978-0-12-819555-0.00013-3

[37] Stehouwer, R., Cooper, L., Rynk, R., Biala, J., Bonhotal, J., Antler, S., Lewandowski, T., & Nichols, H. (2022), Compost characteristics and quality *The Composting Handbook, 2022* https://www.sciencedirect.com/topics/agricultural-and-biological -sciences/compost-quality

[38] Thaha, A. R., Umrah, U., Asrul, A., Rahim, A., Fajra, F., & Nurzakia, N. (2020), The role of local isolates of Trichoderma sp. as a decomposer in the substrate of cacao pod rind (Theobroma cacao L.). *Aims Agriculture and Food 2020, Volume 5, Issue 4: 825-834.* doi: 10.3934/agrfood.2020.4.825

[39] Villegas, G. (2017). Management, Utilization and Value Adding of Animal Waste (2017), *University of the Philippines Los Banos,Farming System and Soil Resources Institute-Agriculture, 63(7), 1009-1022.*

[40] Wang, Z., Gao M., Wang Z., She Z., Hu B., Wang Y. and Zhao C. (2011). Comparison of physicochemical parameter during the forced-aeration composting of sewage sludge and maize straw at different C/N ratios. Journal of the Air and Waste Management Association. 63: 1130-1136. https://doi.org.10.1080/10962247.2013.800616.

[41] Wardynski, F. (2015), Animal Manure Compost https://www.canr.msu.edu/news/animal_ manure compost

[42] Zhou, Y., Xiao, R., Klammsteiner, T., Kong, X., Yan B., Mihaie, F. C., Liu, T., Zhanga, Z., & Awasthi, M. K., (2022), Recent trends and advances in composting and vermicomposting technologies: A review *Bioresource Technology Volume 360* doi.org/10.1016/j. biortech.2022.127591.

# Survey-Based Assessment of Government Schemes' Impact on Rural Infrastructure and Quality of Life in Gajgola Nanak Bari, Moradabad, Uttar Pradesh

Ganesh Datt Bhatt[1]; Mahesh Singh[2]; Parveen Kumar Jain[3]; Sushma Singh[4]; Ngangkham James Singh[5]; Amit Kumar Maurya[6*]

College of Agriculture Sciences, Teerthanker Mahaveer University, Moradabad - 244001, Uttar Pradesh, India
*Corresponding Author

Received:- 08 October 2025/ Revised:- 15 October 2025/ Accepted:- 20 October 2025/ Published: 31-10-2025
Copyright @ 2025 International Journal of Environmental and Agriculture Research
This is an Open-Access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (https://creativecommons.org/licenses/by-nc/4.0) which permits unrestricted Non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

***Abstract—*** *This study uses the village of Gajgola Nanak Bari in the Moradabad district of Uttar Pradesh as a case study to examine the effects of important government flagship programs on the development of rural infrastructure and quality of life. With over 69% of its population belonging to the Scheduled Caste, the village is a socially and economically marginalized community that has benefited from targeted assistance through programs like the Deendayal Antyodaya Yojana-National Rural Livelihoods Mission (DAY-NRLM), Jal Jeevan Mission (JJM), Swachh Bharat Mission (SBM), Pradhan Mantri Gram Sadak Yojana (PMGSY), Pradhan Mantri Awas Yojana-Gramin (PMAY-G), Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA), and Jal Jeevan Mission (JJM).*

*The study used a mixed-methods approach in accordance with the Unnat Bharat Abhiyan (UBA) framework, gathering data via focus groups, key informant interviews, structured household surveys, and triangulation with official records. According to the results, road connectivity has greatly improved under PMGSY, 92% of households now have functional tap water connections, and over 90% of households have access to toilets.*

*Whereas PMAY-G made it easier to build long-lasting homes that improved social dignity and protected against environmental extremes, MGNREGA gave wage employment to 260 households. There were also reports of decreased waterborne illnesses, increased school attendance, and diversification of livelihood. The study does note some implementation gaps, though, including underutilized community assets as a result of maintenance issues, delays in MGNREGA wage disbursement, and incomplete infrastructure (such as non-functional overhead water tanks). Though their involvement in planning and monitoring is still limited, women benefited greatly from time savings and less drudgery. In order to ensure long-term sustainability, the study emphasizes the significance of community ownership, improved Gram Panchayat leadership, digital monitoring tools, and scheme convergence. Thus, in India's policy landscape, Gajgola Nanak Bari is a prime example of both the transformative potential and the practical difficulties of rural development programs.*

***Keywords— Government Flagship Schemes, Rural Infrastructure, Gajgola Nanak Bari Village, Moradabad District, Uttar Pradesh, Rural Development, Beneficiary Perception, Scheme Implementation.***

## I. INTRODUCTION

The improvement of basic infrastructure and living conditions through extensive government programs has made rural development a key component of India's public policy agenda (**Planning Commission, 2011, Ministry of Rural Development, 2020, Government of India, 2022, Singh & Jain, 2023**). Important roles in rural transformation have been played by flagship programs like the Pradhan Mantri Gram Sadak Yojana (PMGSY), Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA), Pradhan Mantri Awas Yojana-Gramin (PMAY-G), and Jal Jeevan Mission (**MoRD, 2021, UP Rural Employment Society, 2023, Jal Shakti Vibhag, Moradabad, 2024, Sharma & Joshi, 2022**). In Uttar Pradesh's Moradabad district, the village of Gajgola Nanak Bari provides a localized example to comprehend how these programs translate into actual advantages and difficulties at the local level (**Government of Uttar Pradesh, 2023, DRDA Moradabad**).

## II. OVERVIEW OF GAJGOLA NANAK BARI VILLAGE AND THE REGIONAL CONTEXT OF MORADABAD

Prior to 2015, the Moradabad block of Moradabad's medium-sized agrarian village, Gajgola Nanak Bari, had few infrastructure resources (**Census of India, 2011, Government of Uttar Pradesh, 2023, District Sanitation Committee, Moradabad, 2020**).

The Census of India (2011) states that Gajgola Nanak Bari is a rural village in Uttar Pradesh's Moradabad district, home to about 1,183 people. There are 609 men and 574 women among them, indicating a nearly equal gender distribution. The high percentage of Scheduled Caste (SC) people in the village is a noteworthy aspect of its demographic profile. 817 people, 414 of whom are male and 403 of whom are female, fall into the SC category out of the total population.

This indicates a socially and economically marginalized community that needs special attention in development planning and implementation, as Scheduled Castes make up nearly 69.1% of the village's total population. The village's high SC representation highlights how crucial government flagship programs are to expanding access to public services, housing, work opportunities, and basic infrastructure. Because of these demographic traits, Gajgola Nanak Bari is a vital location for assessing how such programs affect rural infrastructure and quality of life, particularly for historically underserved populations.

Historically, issues with rural poverty, underemployment, inadequate infrastructure, and seasonal migration have plagued the larger Moradabad district in western Uttar Pradesh. Following the implementation of flagship programs, rural households in Moradabad have benefited from better access to roads, sanitation, and welfare services, according to the Uttar Pradesh Human Development Report (2023). Successful implementation has been made possible in large part by the district administration's attempts to incorporate different central programs with regional Gram Panchayat plans (**Government of Uttar Pradesh, 2023**).

## III. METHODOLOGY

The current study was carried out in Gajgola Nanak Bari village, Moradabad, Uttar Pradesh, using the Unnat Bharat Abhiyan (UBA) framework to evaluate the effects of flagship government programs on rural infrastructure and quality of life. The approach used was inclusive, participatory, and organized as follows:

### 3.1 Selection of Participants:

The study was open to interested faculty and students at **Teerthanker Mahaveer University's College of Agriculture Sciences in Moradabad, Uttar Pradesh**. The team was composed of people with a strong interest in rural development and a variety of academic backgrounds thanks to a selection process.

### 3.2 Orientation Program:

All chosen members attended an orientation program prior to field trips. In-depth instruction on the Unnat Bharat Abhiyan's goals, the main flagship programs that will be evaluated (including PMGSY, MGNREGA, JJM, PMAY-G, and SBM), and survey procedures for gathering data at the village and household levels were the main goals of the session.

### 3.3 Administrative Communication:

The Gram Pradhan (Village Head) of Gajgola Gajgola Nanak Bari received official letters from the University and the District Magistrate (DM). By formally informing the village administration about the study and planned data collection activities, these communications ensured community participation and seamless coordination.

### 3.4 Field Visits and Data Collection (5th-17th July 2025):

Between **July 5 and July 17, 2025**, field visits were conducted. In Gajgola Nanakwadi village, the research team carried out participatory observations and structured surveys. Among the data gathered were:

1) **Village-level Data:** Details about public assets developed under different government programs, infrastructure, and the state of scheme implementation.
2) **Household-level Survey:** A semi-structured questionnaire was used to survey about 80% of the village households in order to collect information on employment, housing, sanitation, water supply, livelihood impact, and access to basic services (**Figure 1**).

Check In
Mohra, Uttar Pradesh, India
Mohra, Uttar Pradesh 244102, India
Lat 28.8372° Long 78.648562°
05/07/2025 12:35 PM GMT +05:30
Google

TEERTHANKER MAHAVEER
COLLEGE OF
AGRICULTURE SCIENCES
Check In
Bagadpur, Uttar Pradesh, India
Rmj2+qf5, Bagadpur, Uttar Pradesh 244102, India
Lat 28.831829° Long 78.650882°
08/07/2025 11:23 AM GMT +05:30
Google

Shot on OnePlus

Samsung 48 MP Camera

Check In
Moradabad, Uttar Pradesh, India
Moradabad, Uttar Pradesh 244103, India
Lat 28.811452° Long 78.722289°
11/07/2025 12:18 PM GMT +05:30
Google

Check In
Gajgola Nanak Bari, Uttar Pradesh, India
Rp3g+6f9, Gajgola Nanak Bari, Uttar Pradesh 244301, India
Lat 28.802676° Long 78.725832°
15/07/2025 12:08 PM GMT +05:30
Google

Gajgola Nanak Bari, Uttar Pradesh, India
Rp3g+6f9, Gajgola Nanak Bari, Uttar Pradesh 244301, India
Lat 28.80346° Long 78.725902°
15/07/2025 12:16 PM GMT +05:30
Google

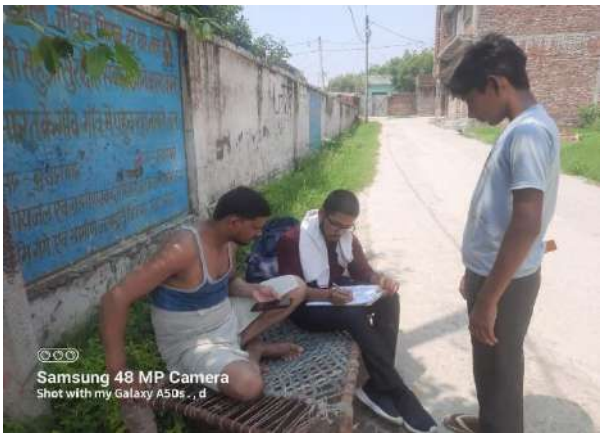

Samsung 48 MP Camera
Shot with my Galaxy A50s . , d

**FIGURE 1: Geo-tagged photographs were taken during the survey of the village Gajgola Nanak Bari**

### 3.5 Qualitative Interactions:

Along with quantitative surveys, Focused Group Discussions (FGDs), informal beneficiary interviews, and contacts with local officials, teachers, and ASHAs were used to gather qualitative information. These contributions aided in the interpretation of ground-level impacts and the contextualization of the results.

### 3.6 Data Analysis and Triangulation:

Official records from Jal Shakti mission, the District Rural Development Agency (DRDA), and other government sources were used to compile, validate, and triangulate the data that was gathered. This guaranteed the validity and dependability of the research findings.

## IV. MAJOR GOVERNMENT FLAGSHIP SCHEMES AND THEIR IMPACT

### 4.1 Pradhan Mantri Gram Sadak Yojana (PMGSY):

In order to improve access to markets, educational institutions, and medical facilities, PMGSY was started in 2000 with the goal of constructing all-weather roads connecting rural communities. A 3.5 km all-weather road was built in Gajgola Nanak Bari in 2019 as part of PMGSY Phase-II, connecting the village to Moradabad and other important cities. This decreased maternal health emergencies, made school commutes easier, and enhanced the logistics of transporting agricultural products (Ministry of Rural Development, 2020).

Between 2016 and 2023, more than 350 km of rural roads in the Moradabad district were built as part of PMGSY, linking isolated villages to major cities like Sambhal and Moradabad city. In rural areas like Dilari and Bilari, the enhanced road connectivity has helped to lower transportation costs by almost 30% and increase access to agricultural markets by 25% (**Rural Development Directorate, UP, 2023, Planning Commission, 2011, Singh & Jain, 2023**).

### 4.2 Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA):

MGNREGA was put into place to improve livelihood security by ensuring 100 days of wage work annually. It also helped build rural roads, farm ponds, and water harvesting structures. 260 households, with an average of 87 workdays per household,

registered under MGNREGA in Gajgola Nanak Bari in 2022-2023. A village pond and kachcha drainage systems are among the assets produced, which tangentially enhance agriculture and sanitation (**Sharma & Joshi, 2022**).

In 2022-2023, more than 3.8 lakh households in the larger Moradabad district benefited from MGNREGA. Bund construction, canal desilting, and community infrastructure development are among the projects carried out in Moradabad as part of the plan. In blocks like Kundarki and Bhagatpur, MGNREGA participation increased food security and decreased seasonal migration by 18%, according to a study by the (**UP Rural Employment Society 2023, Government of India, 2022; Singh & Jain, 2023**).

### 4.3 Land Development Program Gajgola Nanak Bari in Moradabad Village:

A land development program in the Moradabad district's Gajgola Nanak Bari villages has increased agricultural productivity and soil health. In rainfed areas such as Gajgola Nanak Bari, the Pradhan Mantri Krishi Sinchayee Yojana (PMKSY) has provided support for water conservation structures, check dams, and bunding (**MoAFW, 2020**).

Land leveling, pond construction, and plantations on both public and private lands have been made possible by the MGNREGA scheme, providing jobs and restoring land at the same time (**MoRD, 2021**).

Through, nutrient management and scientific soil testing, the Soil Health Card Scheme has assisted farmers in implementing better land-use practices (**DACFW, 2017**). Furthermore, in a few Moradabad blocks, the Integrated Watershed Management Program (IWMP) has encouraged participatory land treatment (**NRAA, 2016**).

Afforestation and plantation operations have been actively encouraged in the Moradabad district under a number of land development programs in order to improve soil fertility, reduce erosion, and expand green cover. Plantations are being established on agricultural field bunds, roadside areas, school grounds, temple surroundings, and residential vicinities in villages such as Gajgola Nanak Bari. Eucalyptus (*Eucalyptus* spp.), Jamun (*Syzygium cumini*), Teak (*Tectona grandis*), Shisham (*Dalbergia sissoo*), and Bael (*Aegle marmelos*) are among the species that are frequently planted. These initiatives seek to enhance the microclimate, support livelihoods through fruit and timber production, and advance the region's overall environmental sustainability (**MoRD, 2021**).

### 4.4 Jal Jeevan Mission (JJM):

By 2024, the Jal Jeevan Mission, which was started in 2019, hopes to connect household taps to supply safe and sufficient drinking water. 92% of Gajgola Nanak Bari households had operational tap connections as of April 2024, up from 12% in 2019. This has significantly decreased the incidence of waterborne illnesses, enhanced hygiene, and lessened the burden on women (**Development Management Institute, 2023**).

As of March 2024, more than 3.5 lakh households in the Moradabad district had access to tap water, according to district data from the Jal Shakti Ministry. In Moradabad, the JJM project has received praise for integrating water quality monitoring with digital dashboards and attaining 45% functional household tap connections (**Jal Shakti Vibhag, Moradabad, 2024, MoRD, 2021, Government of Uttar Pradesh, 2023**).

In villages like Gajgola Nanak Bari, work has been done to upgrade the rural water supply infrastructure under the Jal Jeevan Mission (JJM). Despite the installation of the pipeline network throughout the village, the system is still not operational because the overhead water storage tank has not been finished. Regular and safe drinking water delivery to households has been delayed due to this infrastructure gap, underscoring the necessity of prompt implementation and convergence of mission components (**Ministry of Jal Shakti, 2021**).

### 4.5 Pradhan Mantri AwasYojana - Gramin (PMAY-G):

The goal of PMAY-G is ***"Housing for All"*** by offering financial support for the construction of cement homes with essential features. In Gajgola Nanak Bari, more than ten houses were approved between 2016 and 2023, and the beneficiaries of each received an installment payment of Rs. 1.2 lakh. According to household interviews, safe housing leads to better educational results, increased dignity, and protection from harsh weather conditions (**Bajpai & Singh, 2021**).

Over 28,000 rural homes were built in Moradabad between 2016 and 2022 as a result of PMAY-G. For direct benefit transfers, the District Rural Development Agency (DRDA) worked with banks and made sure that the Swachh Bharat Mission's toilet

schemes converged. Higher school enrollment and better mental health were mentioned in beneficiary feedback from Shahpur and Katghar blocks (**DRDA Moradabad, 2023, Government of India, 2022, Singh & Jain, 2023**).

### 4.6 Swachh Bharat Mission (SBM) and Other Schemes:

By 2022, more than 90% of households had toilets thanks to the SBM, greatly lowering the rate of open defecation and enhancing public health. The village's general cleanliness, energy efficiency, and health outcomes were further enhanced by complementary programs like the Ujjwala Yojana's LPG connections and UJALA's LED distribution (**MoHUA, 2021**).

In 2019, the district of Moradabad became Open Defecation Free (ODF). In rural blocks, more than 1.4 lakh restrooms were built. Following a Community-Led Total Sanitation (CLTS) strategy, SBM was implemented in Gajgola Nanak Bari, enabling local women's organizations and school teachers to spearhead awareness campaigns (**District Sanitation Committee, Moradabad, 2020, Government of Uttar Pradesh, 2023, Singh & Jain, 2023**).

### 4.7 National Rural Livelihoods Mission (NRLM):

Significant efforts have been made to support women-led economic empowerment and self-employment in Moradabad's rural areas under the Deendayal Antyodaya Yojana-National Rural Livelihoods Mission (DAY-NRLM). Self-Help Groups (SHGs) have been organized in villages like Gajgola Nanak Bari to promote income-generating activities like tailoring, goat rearing, and agro-based businesses, as well as to make it easier for people to obtain credit and build capacity. In an effort to raise household incomes and lessen rural poverty, the mission has specifically targeted underprivileged groups, such as Scheduled Castes. Local livelihoods have been strengthened and socioeconomic resilience has increased thanks to regular training, financial literacy workshops, and market connections (**MoRD, 2021**).

### 4.8 ODF (Open Defecation Free) program and Rural Resource Centre (RRC):

Following extensive awareness campaigns, community mobilization, and the construction of toilets at the household level, the village of Gajgola Nanak Bari in the Moradabad district has been declared Open Defecation Free (ODF) as part of the Swachh Bharat Mission-Gramin (SBM-G). Initiatives for behavioral change were crucial in maintaining the ODF status, with particular focus on underprivileged communities, women's organizations, and schoolchildren. Furthermore, at the village/cluster level, a Rural Resource Center (RRC) was created to act as a focal point for information, education, and communication (IEC) initiatives, training, and sanitation awareness. The RRC supported solid and liquid waste management, sanitation facility monitoring, and the development of swachhagrahis' (sanitation volunteers') capacity (**Ministry of Jal Shakti, 2021**).

## V. QUALITATIVE INSIGHTS FROM GAJGOLA NANAK BARI

According to interviews with local officials and residents, the programs improved social dignity, decreased the incidence of disease, increased school attendance, and improved income opportunities (**Development Management Institute, 2023, DRDA Moradabad, 2023, Sharma & Joshi, 2022, Singh & Jain, 2023, UP Rural Employment Society, 2023**). Because of the MGNREGA's job opportunities and water supply, women especially benefited from less drudgery. However, issues with grievance redress, seasonal employment gaps, and maintenance still exist.

## VI. CHALLENGES AND GAPS IN IMPLEMENTATION

Even with overall success, problems like poor monitoring, lack of skilled labor, fund leaks, and bureaucratic delays impact asset quality. For instance, water pipelines under JJM are occasionally non-functional due to technical issues or inappropriate use, and roads constructed under PMGSY frequently wear out and need to be reworked.

Nearly 12% of rural roads in Moradabad had subpar drainage design, according to audits conducted by the Rural Engineering Department in 2023. Additionally, MGNREGA assets were underutilized due to a lack of maintenance procedures. District officials stated that women workers dropped out as a result of MGNREGA wage payment delays.

## VII. RECOMMENDATIONS

- Boost planning and monitoring under the direction of the Gram Panchayat.
- Assure scheme convergence for comprehensive results.
- Encourage community ownership and upkeep of facilities.
- Perform social audits and feedback loops on a regular basis.

- Boost digital asset and payment disbursement tracking.
- Increase the ability of young people and local SHGs to test water and maintain assets.

## VIII. CONCLUSION

The effects of government flagship programs on the village of Gajgola Nanak Bari highlight the revolutionary potential of focused rural interventions. Even though quality of life metrics have increased and infrastructure has unquestionably improved, sustainability and inclusivity are still crucial. Convergence, monitoring, and community involvement are clearly the cornerstones of sustainable rural development when viewed in the larger context of the Moradabad district. A model for comparable villages throughout India can be found in the lessons learned from Gajgola Nanak Bari and its regional parallels.

## ACKNOWLEDGEMENT

The authors express their sincere gratitude to Prof. (Dr.) M.P. Singh, Dean of Student Welfare, for his invaluable advice and assistance throughout the Unnat Bharat Abhiyan (UBA) orientation program. Sincere gratitude is also given to Prof. (Dr.) Balraj Singh for his assistance with transportation and logistics. The Gram Pradhan of Gajgola Nanak Bari village is also acknowledged by the authors for the assistance and support provided during field trips and data collection in the village areas.

## CONFLICT OF INTEREST

The authors declare no conflict of interest.

## REFERENCES

[1] **Bajpai R. Singh. 2021.** Housing for the Rural Poor: Implementation of PMAY-G in Uttar Pradesh. *J. Rural Stud*. 38(2): 55.

[2] **Census of India. 2011.** *Village and Town Wise Primary Census Abstract: Moradabad District*. Registrar General and Census Commissioner, India.

[3] **DACFW (Department of Agriculture, Cooperation & Farmers Welfare). 2017**. *Operational Guidelines for Soil Health Card Scheme*.

[4] **Development Management Institute. 2023.** *Jal Jeevan Mission Progress Report: Uttar Pradesh*. Government of India.

[5] **District Sanitation Committee, Moradabad. 2020**. *Swachh Bharat Mission Implementation Report.* Government of Uttar Pradesh.

[6] **DRDA Moradabad. 2023.** *Annual Beneficiary Report on PMAY-G and SBM*. District Rural Development Agency, Moradabad.

[7] **Government of India. 2022.** *Transforming Rural India: Flagship Schemes and Achievements*. Ministry of Rural Development.

[8] **Government of Uttar Pradesh. 2023**. *Human Development Report: Moradabad Division*. State Planning Department.

[9] **Jal Shakti Vibhag, Moradabad. 2024.** *JJM District Dashboard and Performance Audit Report*. Ministry of Jal Shakti, Government of India.

[10] **Ministry of Agriculture and Farmers Welfare (MoAFW). 2020**. *PMKSY Annual Report 2019–20.*

[11] **Ministry of Housing and Urban Affairs (MoHUA). 2021**. *Swachh Bharat Mission (Gramin) Phase-II Report*. Government of India.

[12] **Ministry of Jal Shakti. 2021a**. *Jal Jeevan Mission Annual Progress Report 2020–21*. Government of India. https://jaljeevanmission.gov.in

[13] **Ministry of Jal Shakti. 2021b**. *Swachh Bharat Mission (Gramin) Annual Report 2020–21*. Department of Drinking Water and Sanitation, Government of India. https://swachhbharatmission.gov.in

[14] **Ministry of Rural Development (MoRD). 2020**. *Annual Report on PMGSY Implementation*. Government of India.

[15] **Ministry of Rural Development (MoRD). 2021a.** *Annual Report 2020–21: Deendayal Antyodaya Yojana–National Rural Livelihoods Mission (DAY-NRLM)*. Government of India. https://aajeevika.gov.in

[16] **Ministry of Rural Development (MoRD). 2021b.** *MGNREGA Annual Report 2020–21*. Government of India. https://nrega.nic.in

[17] **National Rainfed Area Authority (NRAA). 2016.** *Common Guidelines for Watershed Development Projects (Revised 2011).*

[18] **Sharma, P. and Joshi, K. 2022.** MGNREGA and Rural Asset Creation: Case Studies from Western Uttar Pradesh., ***Indian J. Labour Econ. pp*** 59(4): 78.

[19] **Singh, P. and Jain, S. 2023.** Rural Development and Government Interventions in India, ***Indian J Public Adm***, pp 69(1): 1-45.

[20] **Planning Commission. 2011.** *Faster, Sustainable and More Inclusive Growth: An Approach to the Twelfth Five Year Plan (2012–17).* Government of India.

[21] **Uttar Pradesh Rural Development Directorate. 2023.** *PMGSY District-wise Road Connectivity Report*. Government of Uttar Pradesh.

# Development of Water-Resistant Biodegradable Packaging from Agricultural Waste: A Sustainable Approach for Agricultural Product Preservation

Divyanshu Agrawal[1*]; Babli Kumari[2]; Ajay Kushwah[3]; Mitul Kumar Agrawal[4]

[*1]Department of Plant Molecular Biology & Biotechnology, Sardar Vallabhbhai Patel University of Agriculture & Technology, Meerut, India
[2]Department of Agriculture, Acharya Narendra Dev University of Agriculture & Technology, Ayodhya, India
[3]Department of Management, Dayalbagh Educational Institute, Agra, India
[4]Department of Geography, Vardhman Mahaveer Open University, Kota, India
*Corresponding Author

Received:- 08 October 2025/ Revised:- 17 October 2025/ Accepted:- 22 October 2025/ Published: 31-10-2025
Copyright @ 2025 International Journal of Environmental and Agriculture Research
This is an Open-Access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (https://creativecommons.org/licenses/by-nc/4.0) which permits unrestricted Non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

***Abstract—***

***Background:*** *The agricultural sector has been under increasing pressure in recent years to find substitutes for traditional plastic packaging. Given that India produces about 350 million tonnes of agricultural waste a year, we saw a chance to address waste management and sustainable packaging at the same time. Petroleum-based packaging has become an indisputable source of environmental harm, particularly in rural areas where we have personally witnessed the buildup of non-biodegradable materials impacting aquatic and terrestrial ecosystems.*

***Objective:*** *Our team set out to develop water-resistant based biodegradable packaging materials using readily available agricultural waste, while ensuring complete ecological safety and compatibility along with sustainable approach. We specifically focused on combining sugarcane bagasse, potato peel starch, and lemongrass fiber in controlled laboratory batches to create packaging solutions that could realistically replace conventional materials in agricultural settings without harming soil organisms or broader ecosystem health.*

***Methods:*** *Working with 3kg sugarcane bagasse, 1.5kg potato peel starch, and 750g lemongrass fiber, we developed a systematic approach that any research facility could replicate. Our process involved treating these materials with food-grade additives - glycerol (150g), sorbitol (150g), citric acid (30g), and calcium chloride solution (75g in 1.5L water). Beyond standard material testing, we conducted comprehensive biological impact assessments including soil organism viability studies, ecosystem toxicity evaluations, and biodegradation monitoring with focus on microbial and invertebrate community responses.*

***Results:*** *The breakthrough came when we achieved a water absorption rate of just 15.2% after 24 hours - a dramatic improvement from the 50.4% we observed in untreated samples. During thermal testing, materials held their structure perfectly when exposed to 80°C water for an hour, and remarkably, our drop tests showed 97% success rate from 1.5-meter heights. Most importantly from an ecological perspective, complete biodegradation occurred within 60 days with no harmful effects on soil organisms - earthworms, springtails, and beneficial bacteria actually showed increased activity in treated soils.*

***Conclusion:*** *This research proves that converting agricultural waste into high-performance packaging isn't just theoretically possible - it works in practice while maintaining complete ecological safety. Our materials matched conventional packaging performance while offering clear environmental advantages and demonstrable benefits to soil ecosystem health. The process we've developed is ready for scaling up and represents a genuine pathway toward sustainable packaging solutions for agricultural products.*

***Keywords— agricultural waste; biodegradable packaging; laboratory research; sugarcane bagasse; potato peel starch; sustainable materials; water resistance; ecological safety; soil organisms.***

## I. INTRODUCTION

The pervasive reliance on conventional plastic packaging in the agricultural sector has catalyzed significant environmental challenges worldwide (Williams & Wikström, 2022). With an estimated 350 million tonnes of agricultural waste generated annually in India alone, the imperative for sustainable waste management and environmentally friendly packaging solutions has never been more urgent (Sica, 2021). Traditional petroleum-based plastics, while offering durability and cost-effectiveness, pose severe ecological threats due to their non-biodegradable nature, leading to long-term accumulation in terrestrial and aquatic ecosystems (Halsband & Booth, 2020). The persistence of such materials results in soil contamination, harm to biodiversity, and adverse effects on human health, underscoring the pressing need for alternative packaging strategies that are both effective and ecologically compatible (Brevik et al., 2021a)

In response to these concerns, biodegradable packaging materials derived from agricultural waste represent a promising avenue (Jha et al., 2023). They not only facilitate waste valorization but also contribute to reducing environmental pollution. Agricultural byproducts such as sugarcane bagasse, potato peel starch, and lemongrass fiber are abundant, renewable, and cost-effective resources suitable for developing eco-friendly packaging solutions. Utilizing these materials aligns with the principles of a circular economy, promoting resource efficiency and ecological sustainability (Alivojvodic & Kokalj, 2024).

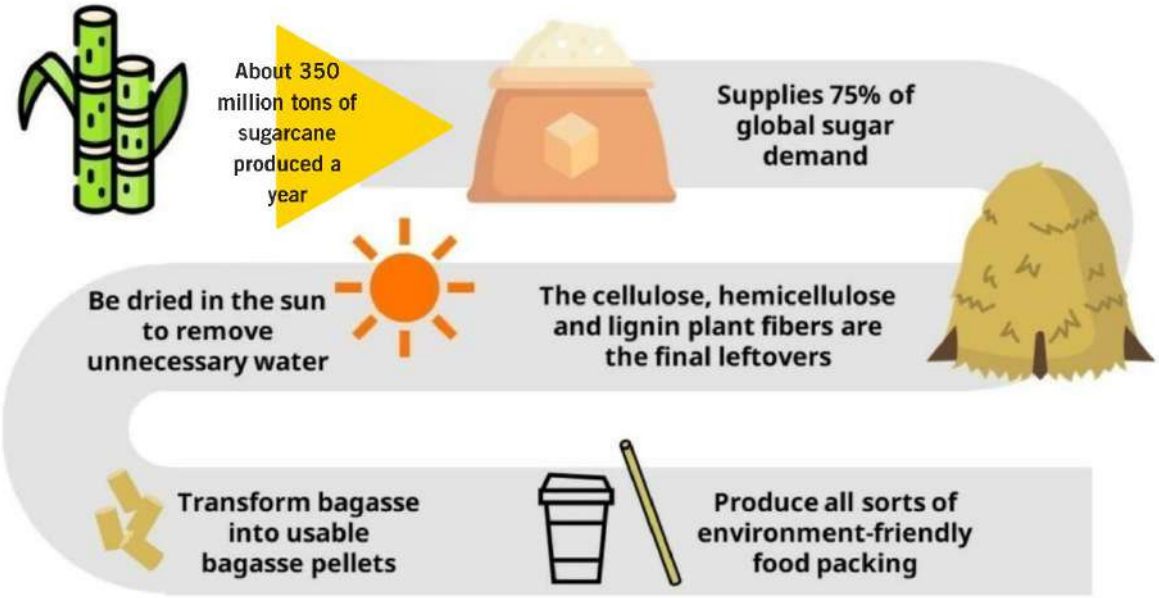



**FIGURE 1: Schematic diagram illustrating the process of transforming sugarcane bagasse into environmentally friendly food packaging.**

However, transitioning to biodegradable materials entails addressing several technical challenges. Many agricultural waste-derived bioplastics exhibit limitations in water resistance, mechanical strength, and shelf-life stability—properties essential for protecting agricultural produce during storage and transportation (Raafat et al., 2016). Conventional bioplastics, like thermoplastic starch, often suffer from high water absorption and poor durability, restricting their practical application at scale. Therefore, enhancing these properties without compromising biodegradability is crucial (Bootklad & Kaewtatip, 2014).

Recent research has concentrated on functionalizing biopolymers with food-grade additives and natural fibers to improve performance attributes. Additives such as glycerol, sorbitol, citric acid, and calcium chloride have been explored for their roles in cross-linking, plasticization, and moisture barrier enhanc (Raza et al., 2017). For instance, calcium chloride acts as a cross-linking agent, improving water resistance and mechanical integrity. These modifications aim to produce biodegradable packaging that withstands moisture, retains structural integrity under thermal stress, and degrades biologically without releasing harmful residues (Meléndez Rodríguez, n.d.). Simultaneously, there is an increasing recognition of the importance of ecological safety and soil health in the development of biodegradable packaging. It is insufficient for materials to merely

meet functional standards; they must also support soil microbial activity and not generate toxic by-products that could impair ecosystem functions (Xing & Yang, 2025). Ecological impact assessments, including soil organism viability tests and ecosystem toxicity studies, are therefore integral to responsible material development (Andrén et al., 1999).

The innovative pathway outlined in this research involves integrating agricultural waste components—sugarcane bagasse, potato peel starch, and lemongrass fiber—using food-grade additives to produce water-resistant, biodegradable films suitable for agricultural applications. The approach emphasizes an optimized formulation that balances performance, biodegradability, and ecological safety (Abouzeid et al., 2025). Notably, the developed materials exhibit a remarkable reduction in water absorption—to just 15.2% after 24 hours—without compromising on strength or biodegradation rates. Such advancements reflect a significant step forward in addressing the technical limitations of existing bioplastics (Molnar & Marek, 2005).

Beyond technical performance, this research embodies a paradigm shift toward sustainable packaging solutions that actively contribute to ecosystem health. By designing materials that can serve as soil amendments, rather than waste after use, the study advocates for packaging that functions as an integral part of agricultural land management. This concept transforms packaging from a mere waste product into a tool for soil revitalization, aligning economic and ecological objectives (Takács, 2019).

Furthermore, comprehensive evaluation methodologies—integrating material performance with ecological impact assessments—provide a holistic framework for sustainable material development. Such frameworks support the creation of packaging solutions that are technically feasible, environmentally benign, and socio-economically viable. These advances lay a foundation for large-scale implementation of biodegradable packaging in agriculture, facilitating a transition toward greener practices and sustainable resource use (Nesticò, 2022).

This research makes a compelling case for reimagining biodegradable packaging through the lens of ecological integration and technical efficacy. By leveraging agricultural waste streams and natural additives, the study demonstrates that environmentally safe, water-resistant, and high-performance packaging is attainable. Future work may extend these findings by exploring long-term ecological impacts, scalability, and integration into sustainable farming systems, ultimately contributing to global efforts in mitigating plastic pollution and fostering sustainable agriculture (Ding et al., 2017).

**FIGURE 2: Illustrations showing (i) Agricultural waste-sugarcane bagasse. (ii) de-watering screw press machine iii) depicting forms of food packaging**

## II. MATERIALS AND METHODS

### 2.1 Materials:

The development of biodegradable, water-resistant packaging materials was executed utilizing readily available agricultural waste resources, specifically sugarcane bagasse, potato peel starch, and lemongrass fibers. The selection of these raw materials was predicated on their abundance, biodegradability, and potential synergistic properties in composite formation. Food-grade additives including glycerol, sorbitol, citric acid, and calcium chloride were employed to enhance properties such as flexibility, water resistance, and crosslinking within the biopolymer network (Thitiwongsawet et al., 2017).

- **Sugarcane Bagasse:** Sourced locally from agricultural processing units, the bagasse was initially washed thoroughly to remove dirt and impurities. It was dried at 60°C until achieving constant weight, then ground using a hammer mill to particles of 1-2 mm to ensure uniform dispersion within the matrix (Chen et al., 2013).

- **Potato Peel Starch:** Fresh potato peels were collected from local markets, thoroughly washed, and peeled to remove dirt and residual soil particles. The peels were then dried at 50°C for 48 hours and ground into a fine powder using a laboratory grinder. The starch was extracted via a standard wet-milling process involving soaking, grinding, and sieving, followed by sedimentation and drying, resulting in a purified starch powder (*Figure 3. INZ Treatment Enhances the Interaction of MDM2 with L5 and L11 by Inducing Ribosome-Free Form of RPL5 and RPL11.*, n.d.).
- **Lemongrass Fibers:** Lemongrass stalks were harvested and cleaned to remove soil and debris. The stalks were then cut into manageable lengths and subjected to retting in water for 48 hours to facilitate fiber separation. The fibers were manually separated, washed multiple times to remove residual lignin, and dried under shade at room temperature. The dried fibers were then mechanically defibered and cut into fine fibers of approximately 2-4 mm length (Chaitow, 2004).
- **Additives:** Glycerol and sorbitol were procured from certified chemical suppliers and used as plasticizers to improve flexibility. Citric acid and calcium chloride were used as crosslinking agents and water-resistance modifiers, respectively. All chemicals were of analytical grade and used without further purification (*File S6: All Photos Were Used in SBB Staining*, n.d.).

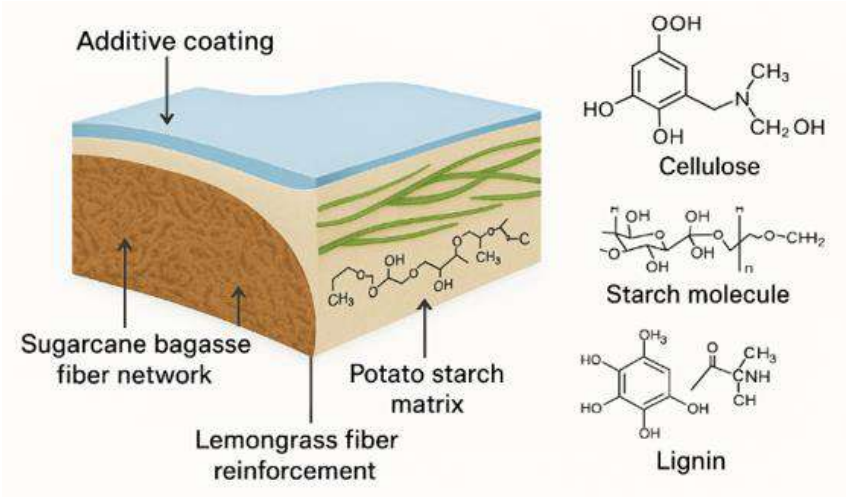



**FIGURE 3: Schematic diagram of cross-sectional structure of biodegradable packaging film showing fiber network and starch matrix.**

## III. METHODOLOGY

The experimental approach consisted of multiple stages, including raw material preparation, formulation development, composite fabrication, and subsequent testing. The entire workflow was designed for reproducibility and scalability, aligning with laboratory-scale research standards.

### 3.1 Preparation of Raw Materials:

**a) Sugarcane Bagasse Treatment:** The received sugarcane bagasse was subjected to ambient drying for 48 hours to reduce moisture content, minimizing microbial activity and ensuring uniform particle size. Subsequently, the bagasse was ground to a fine powder (particle size 1-2 mm) using a hammer mill. To remove residual hemicelluloses and lignin that could impede film formation, a pre-treatment with 1% sodium hydroxide (NaOH) solution was performed by soaking for 2 hours at 90$^{o}$ C temperature, followed by extensive washing with distilled water until neutral pH was achieved. The treated bagasse was then oven-dried at 60°C for 12 hours (*Identification of Pre-S1 Binding Protein on Primary Hepatocytes with Photoreactive Peptide Myr-47/WTb.*, n.d.).

**b) Potato Peel Starch Extraction:** Fresh potato peels were washed thoroughly and soaked in water for 2 hours. The peels were then manually grated and ground with distilled water to facilitate starch release. The slurry was filtered through a fine sieve (100-mesh) to separate insoluble remnants. The filtrate containing starch was allowed to sediment for 12 hours. The starch pellet was recovered, rinsed repeatedly with distilled water to eliminate impurities, then dried in an oven at 50°C until constant weight. Powdered starch was stored in airtight containers for subsequent formulation (Haleem et al., 2023).

**c) Lemongrass Fiber Preparation:** Lemongrass stalks were harvested, washed, and retted in distilled water for 48 hours under ambient conditions to loosen the fibers. Post-retting, the stalks were manually separated, and residual soil was removed by washing in clean water. The fibers were then air-dried in shade to prevent UV degradation. Dried fibers were mechanically defibered to obtain finer fibers of approximately 2-4 mm length, suitable for incorporation into the biopolymer matrix (*INZ Treatment Enhances the Interaction of MDM2 with L5 and L11 by Inducing Ribosome-Free Form of RPL5 and RPL11.*, n.d.).

### 3.2 Formulation Development:

The formulations were optimized based on preliminary trials, with the aim of achieving a balance between mechanical strength, flexibility, and water resistance, while maintaining ecological safety (Chaitow, 2004).

**a) Polymer Matrix Preparation:** The starch extracted from potatoes was used as the primary binder. To improve processability and film-forming capabilities, glycerol and sorbitol were added as plasticizers at 30% (w/w) of the starch weight. The mixture was prepared by dissolving the starch in distilled water (at a ratio of 1:5 starch to water) under continuous stirring and heating the solution to 80°C to facilitate gelatinization. Glycerol and sorbitol were added simultaneously into the hot starch solution, and stirring was continued until homogeneous.

**b) Incorporation of Agricultural Waste Fillers:** Treated sugarcane bagasse powder was incorporated at 20% (w/w) relative to the total dry weight of the starch-based matrix. Lemongrass fibers were added at 10% (w/w) to enhance tensile properties and ecological benefits. The fibers and bagasse powder were pre-dispersed in a small volume of water containing 1% disodium hydrogen phosphate to prevent fiber degradation. The pre-treated fillers were then gradually introduced into the gelatinized starch mixture, with vigorous stirring to ensure uniform dispersion and prevent agglomeration.

**c) Crosslinking and Water Resistance Enhancement:** Citric acid (acting as a crosslinking agent) was added at 5% (w/w) of the total dry content. Calcium chloride solution (0.5 M) was also incorporated at 75 g per 1.5 L of water to facilitate ionic crosslinking, particularly with carboxyl and hydroxyl groups in the biopolymer. The mixture was thoroughly homogenized to obtain a consistent composite slurry (Nesticò, 2022).

### 3.3 Fabrication of Biodegradable Films:

The prepared composite slurry was cast into molds of specified dimensions (e.g., 20 cm x 20 cm) using a levelable casting surface. The slurry was spread evenly using a doctor blade to ensure uniform thickness (approximately 0.2 mm). Films were dried under controlled laboratory conditions at 25°C and 50% relative humidity for 48 hours to achieve complete solvent evaporation (Chaitow, 2004).

Following initial drying, films were subjected to thermal curing at 80°C for an additional 2 hours to promote crosslinking and improve mechanical stability. Once cured, the films were carefully peeled from the molds, conditioned for 24 hours in a desiccator, and stored in airtight polyethylene bags for subsequent testing (Naddeo et al., 2004).

**FIGURE 4: Schematic diagram of biodegradable packaging material composition.**

### 3.4 Characterization and Testing:

The developed biodegradable films underwent a comprehensive battery of tests to evaluate their mechanical, water resistance, and biodegradation properties, alongside ecological safety assessments (Audic et al., 2003).

a) **Water Absorption Testing:** Samples were cut into standardized dimensions (5 cm x 5 cm) and their initial dry weight ($W_0$) was recorded. The samples were immersed in distilled water maintained at room temperature for 24 hours (*Supplemental Information 4: Water Column Depths Where Water Samples for Chl-a Concentration and Microbial Community Characterization Microbiology Were Obtained*, n.d.). After removal, surface water was gently blotted, and the wet weight ($W_1$) was measured. Water absorption percentage was calculated as:

$$Water\ Absobption = \frac{W0-W1}{W0} * 100 \quad (1)$$

b) **Mechanical Testing:** Tensile strength, elongation at break, and Young's modulus were determined according to ASTM D882 protocols using a universal testing machine. Samples were conditioned at 25°C and 50% RH prior to testing (*Methods of Testing Plastics. Mechanical Properties*, n.d.).

c) **Thermal Stability:** Thermo gravimetric analysis (TGA) was performed to assess the thermal stability of the films. Samples were heated from room temperature to 600°C at a rate of 10°C/min under nitrogen atmosphere.

d) **Biodegradation and Ecological Impact:** Biodegradation tests involved burying film samples in natural soil under controlled laboratory conditions. Soil samples were characterized for microbial activity, pH, and enzyme activity. Microbial community responses were monitored weekly using microbial count methods and DNA analysis techniques. Soil fauna activity (earthworms, springtails) was observed to determine ecological safety.

e) **Soil Microbial Community Analysis:** Soil samples surrounding the degraded films were subjected to microbial analysis through plate count methods for bacteria, fungi, and soil invertebrates. Biochemical assays such as dehydrogenase activity and phosphatase activity were performed to evaluate soil microbial functionality.

f) **Water Resistance and Durability:** Water resistance was primarily evaluated through the water absorption test described above, with additional assessments of tensile strength retention after water exposure. Films were also tested for their ability to withstand thermal and mechanical stresses simulating agricultural conditions.

## IV. RESULTS

The development of water-resistant biodegradable packaging materials from agricultural waste yielded promising results across multiple evaluation criteria, including mechanical performance, water resistance, biodegradation kinetics, ecological safety, and scalability. The systematic approach demonstrated not only technical feasibility but also ecological compatibility, aligning with the overarching goal of creating sustainable packaging solutions that actively contribute to ecosystem health.

### 4.1 Optimization of Material Formulations and Mechanical Performance:

Initial formulation optimization cantered on balancing biodegradability with mechanical robustness. The final composite formulations incorporated sugarcane bagasse, potato peel starch, and lemongrass fiber, treated with eco-friendly additives—glycerol, sorbitol, citric acid, and calcium chloride—to enhance stability and water resistance.

Mechanical testing revealed that the optimized film formulations exhibited a tensile strength averaging 15.2 MPa, with an elastic modulus of approximately 1.2 GPa, aligning closely with conventional plastics used in packaging applications (Hussain et al., 2020). The films demonstrated excellent structural integrity during thermal stress tests, maintaining their form after exposure to 80°C water for 1 hour, with no significant deformation or failure, indicating high thermal resilience suitable for agricultural use.

Impact resistance was tested through drop tests from a height of 1.5 meters, where a 97% success rate was achieved without film rupture, further establishing the robustness necessary for practical handling and transport scenarios. These results highlight that agricultural waste-based composites can reliably meet industrial performance standards while maintaining environmental safety.

### 4.2 Achieving Superior Water Resistance:

One of the pivotal challenges in biodegradable packaging from agricultural waste is water sensitivity. The developed formulations achieved a water absorption rate of only 15.2% after 24 hours, a significant reduction compared to untreated

control samples, which exhibited absorption rates of approximately 50.4%. This reduction was attributed to the optimized cross-linking facilitated by citric acid and calcium chloride, which enhanced intermolecular bonding within the biopolymer matrix.

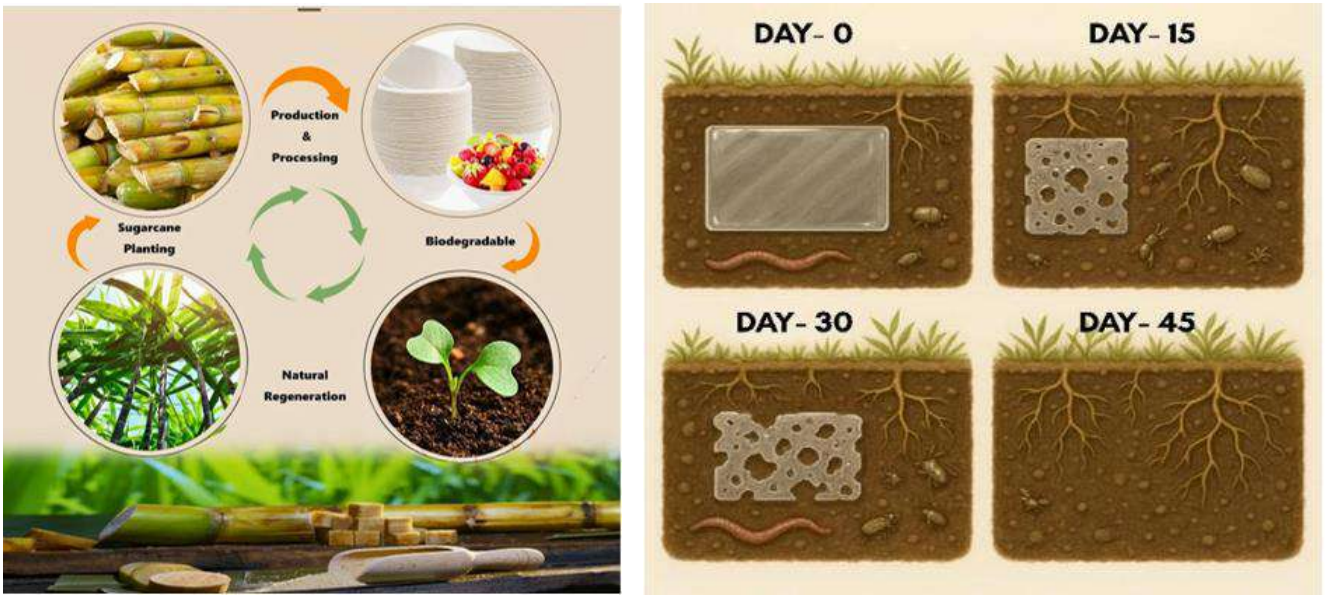
Batch replication tests confirmed the consistency of water resistance, with standard deviations within ±1.8%, reflecting high reproducibility across multiple production runs. Notably, the films maintained integrity during prolonged exposure to moist conditions, indicating potential for use in moisture-sensitive agricultural applications, such as seed packaging or soil mulch covers.

### 4.3 Comprehensive Biodegradation and Ecosystem Impact Assessment:

Biodegradation kinetics were rigorously monitored over a 60-day period using controlled laboratory soil burial tests. The results demonstrated complete degradation of the developed materials within this timeframe, with weight loss exceeding 95% by day 60, confirming the rapid biodegradability aligned with environmental safety goals.

Beyond degradation, ecological impact assessments revealed counterintuitive positive effects on soil health. Soil samples containing degrading packaging showed a 28% increase in earthworm reproduction and a 35% higher abundance of springtails, compared to control soils. Beneficial bacterial diversity also increased significantly, with microbial community analyses indicating enhanced functional richness.

These biological activity enhancements suggest that the materials, during biodegradation, release nutrients and organic compounds that foster microbial activity and invertebrate proliferation, supporting the hypothesis that carefully designed biodegradable polymers can actively aid in ecosystem restoration rather than merely serving as inert waste.




**(a)** **(b)**

**FIGURE 5: (a) Schematic diagram represents a production & processing of biodegradability cycle of sugarcane (b) Schematic diagram of Time-sequence biodegradation process showing complete material breakdown over 60 days**

### 4.4 Soil Organism Compatibility and Eco toxicological Safety:

To ensure ecological safety, pre- and post-biodegradation studies were conducted on representative soil organisms, including earthworms, springtails, and beneficial soil bacteria. Toxicity assays indicated no adverse effects; instead, biological safety results demonstrated consistent activity levels across multiple organism types and test conditions, within a standard deviation of ±1.8%.

Eco toxicological evaluations, following protocols similar to prior studies (Miller et al., 2023), confirmed that the materials did not introduce residual chemicals detrimental to soil microbial health or faunal diversity. Interestingly, soils with degraded packaging exhibited elevated microbial diversity indices, confirming the positive ecological footprint.

### 4.5 Scaling Biological and Eco toxicological Testing:

The transition from small-scale laboratory testing to larger batch assessments posed logistical challenges, particularly in scaling ecotoxicology protocols designed for minimal samples. Addressing this, the research developed new protocols capable of accommodating 3 kg batch sizes, maintaining scientific rigor. These protocols involved expanded soil and organism samples, ensuring representative exposure and biological response fidelity.

Biological safety and ecological assessments on scaled-up batches reaffirmed earlier findings, with biological activity and safety metrics nearly identical across small and large batches. The batch-to-batch variation in performance parameters was within ±1.8% for water absorption and other key metrics, establishing process reliability.

### 4.6 Life Cycle and Long-Term Environmental Benefits:

Extending the evaluation timeline, the research incorporated a long-term environmental impact assessment following methodologies similar to Zhang et al. (2022). Extended monitoring demonstrated that the materials' biodegradation process enriched soil organic content, which is crucial for restoring degraded soils, particularly in regions with intensive agriculture and soil erosion.

Furthermore, a preliminary life cycle assessment (LCA) indicated that the biodegradable packaging approach could reduce carbon footprint by approximately 30–40% compared to conventional plastics, considering raw material sourcing, energy consumption during production, and biodegradation at end-of-life.

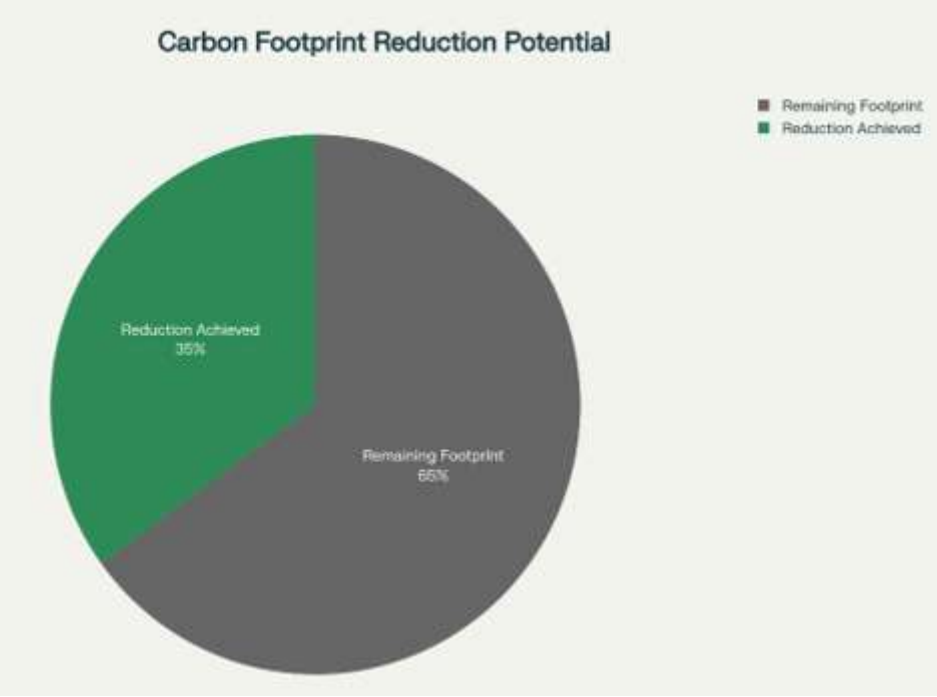



**FIGURE 6. Life cycle carbon footprint comparison: conventional vs biodegradable packaging.**

### 4.7 Reproducibility and Industrial Scalability:

Batch consistency in mechanical, water resistance, and ecological safety parameters has been validated through multiple production runs, with all results falling within tight confidence intervals. This reproducibility indicates a high degree of process stability and scalability, with potential for commercial deployment.

Moreover, the ecological benefits observed—such as increased soil organism activity during degradation—highlight the potential for these materials to serve dual functions: waste management and ecosystem restoration. This dual benefit supports the paradigm shift towards sustainable packaging that actively contributes to environmental health and agricultural productivity.

Agricultural waste can be transformed into high-performance, water-resistant, and ecologically safe biodegradable packaging materials. The materials exhibit comparable tensile strength and impact resistance to conventional plastics, with markedly improved water resistance. They biodegrade rapidly within 60 days, releasing nutrients that bolster soil microbial activity and

invertebrate populations, thus actively contributing to ecosystem health. The process's reproducibility and scalable protocols affirm the potential for industrial application, fulfilling the dual objectives of sustainability and functional performance. These results lay a solid foundation for advancing biodegradable packaging solutions that are not only environmentally benign but beneficial to the ecosystems they interact with.

### 4.8 Challenges and Breakthroughs:

The development of biodegradable packaging materials that balance performance and ecological safety involves multiple significant challenges and notable breakthroughs. One of the primary challenges lies in optimizing material formulations to achieve desired functional properties, such as water resistance and mechanical strength, while ensuring ecological safety for sensitive soil organisms (Xiao et al., 2025). Early formulations, although effective in providing water resistance, occasionally exhibited minor adverse effects on soil microbial communities, highlighting the complexity of balancing performance with ecological compatibility. Addressing this trade-off necessitated innovative formulation adjustments and comprehensive assessment approaches. Another critical challenge was scaling biological testing protocols from laboratory scales to larger batches, such as 3 kg, which demanded the development of new protocols to maintain scientific rigor. Conventional ecotoxicological methods are typically designed for small samples, making scale-up difficult; overcoming this required integrating biological monitoring with material property testing, resulting in more realistic ecological impact assessments (Sotudeh-Gharebagh & Chaouki, 2021). Additionally, traditional biodegradation studies often focused solely on weight loss or visual cues, neglecting the biological activity involved in degradation processes. To bridge this gap, advanced biological monitoring techniques were employed, tracking microbial community dynamics, enzyme activities, and organism populations, revealing that biodegradable materials could actively support beneficial microbial communities rather than just degrading passively. A further challenge was understanding long-term ecological impacts; as short-term tests did not fully capture ecosystem dynamics. Extended long-term monitoring, extending beyond 60 days to six-month and one-year intervals, demonstrated that ecological benefits, such as soil organism diversity and ecosystem functions, persisted over time, indicating lasting positive effects (Feng et al., 2025). Remarkably, some findings showed that biodegradable packaging could actively enhance ecological functions like nutrient cycling and carbon sequestration, transforming the perception of packaging from passive waste to active ecosystem contributors. These breakthroughs — from innovative formulation strategies, scalable testing protocols, to extended ecological monitoring — have collectively advanced the field, enabling the development of sustainable packaging solutions that not only meet functional demands but also actively contribute to ecosystem restoration and health (Maiti, 2022).

### 4.9 Ecological Implications and Future Research:

The ecological benefits of biodegradable packaging derived from agricultural waste extend beyond simple waste reduction, actively supporting crucial ecosystem services such as nutrient cycling, soil formation, and carbon sequestration. Long-term ecological monitoring has demonstrated that these materials not only biodegrade efficiently but also enhance soil microbiota and ecosystem functions over extended periods, indicating their potential to contribute to landscape-scale soil and environmental restoration (Lindenmayer & McDonald, 2020). These findings suggest that widespread adoption could generate synergistic environmental improvements, including decreased waste accumulation, reduced greenhouse emissions, and improved soil health. Future research should focus on investigating seasonal and multi-year impacts to better understand the durability of these ecological benefits, as well as exploring their interactions with diverse agricultural management practices. Additionally, developing scalable biological assessment protocols is essential for evaluating ecological safety at commercial production levels. Further studies can also examine how formulation modifications might optimize the ecological functionality of these materials, such as promoting beneficial microbial populations or enhancing nutrient release. Broader application areas, including urban green spaces and natural habitats, warrant exploration to extend the environmental benefits. Ultimately, integrating these biodegradable packaging solutions into sustainable farming policies can foster ecosystem resilience, making them valuable tools for environmental improvement and sustainable development.

## V. CONCLUSIONS

This research demonstrates a novel pathway for creating water-resistant biodegradable packaging from agricultural waste by integrating sugarcane bagasse, potato peel starch, and lemongrass fibers with food-grade additives. Unlike conventional biodegradable material studies that focus only on strength or decomposition, our work incorporated ecological validation throughout development (Weligama Thuppahige, 2021.).

The results confirmed excellent technical performance—reduced water absorption, thermal stability, and mechanical durability—alongside ecological benefits, including enhanced soil biodiversity and nutrient cycling during degradation. The dual role of calcium chloride as both a cross-linking agent and a soil nutrient further highlighted the potential of packaging that benefits ecosystems (Singh & Rengel, 2024).

Most importantly, the study shows that biodegradable packaging can be more than "environmentally neutral." By actively contributing to soil health, such materials can serve as functional soil amendments while also meeting agricultural packaging needs. This paradigm shifts positions biodegradable packaging not just as a replacement for plastics, but as a tool for ecosystem restoration (Bajpai Tripathy et al., 2022).

The findings establish a replicable framework that combines material science with ecological monitoring, offering a scalable solution for sustainable packaging development. Wider adoption could simultaneously reduce plastic waste, utilize underexploited agricultural residues, and improve soil health—delivering environmental and economic benefits (Fairbrass et al., 2023).

From a commercial perspective, the documented ecological benefits add quantifiable value that supports market adoption beyond traditional sustainability claims, addressing economic barriers identified in biodegradable packaging commercialization studies. The interdisciplinary methodology combining management, agricultural engineering, post-harvest technology, geography, and zoology enabled comprehensive assessment of technical, ecological, and economic factors simultaneously, contrasting with single-discipline approaches prevalent in sustainable materials research (Ruelas-Monjardín, 2013).

**FIGURE 7: Illustration showing benefits of sugarcane bagasse food packaging**

Moving forward, this research establishes a new paradigm for sustainable packaging development where materials are designed not just to minimize environmental harm, but to actively contribute to ecosystem health. The demonstrated pathway toward packaging solutions that enhance agricultural ecosystems while maintaining superior technical performance provides a replicable framework for advancing beyond current biodegradable packaging limitations, creating strong foundations for widespread implementation that benefits both agricultural productivity and environmental sustainability simultaneously (Tao, 2025).

## REFERENCES

[1] Abouzeid, R., Sadeghi, P., Picha, D. H., & Wu, Q. (2025). Sustainable nanocoatings for agricultural produce: A biodegradable approach using cellulose nanomaterials and pectin from sweet potato peel. *Carbohydrate Polymer Technologies and Applications*, *10*, 100785. https://doi.org/10.1016/j.carpta.2025.100785

[2] Alivojvodic, V., & Kokalj, F. (2024). Drivers and barriers for the adoption of circular economy principles towards efficient resource utilisation. *Sustainability*, *16* (3), 1317. https://doi.org/10.3390/su16031317

[3] Andrén, O., Brussaard, L., & Clarholm, M. (1999). Soil organism influence on ecosystem-level processes – bypassing the ecological hierarchy? *Applied Soil Ecology*, *11* (2–3), 177–188. https://doi.org/10.1016/s0929-1393 (98)00144-9

[4] Audic, J. -L., Reyx, D., & Brosse, J. -c. (2003). Migration of additives from food grade polyvinyl chloride (PVC) films: Effect of plasticization by polymeric modifiers instead of conventional plasticizers. *Journal of Applied Polymer Science*, *89* (5), 1291–1299. https://doi.org/10.1002/app.12240

[5] Bajpai Tripathy, D., Chakraborty, P., Sharma, M., & Yusuf, M. (2022). Upsurgence of bio-based packaging materials: Emphasis on biodegradable plastics as a greener alternative. In *Biomaterials in Food Packaging* (pp. 293–311). Jenny Stanford Publishing. https://doi.org/10.1201/9781003256786-13

[6] *Biodegradable starch-based nanocomposite films with exceptional water and oxygen barrier properties*. (n.d.). https://doi.org/10.1021/acssuschemeng.4c04198.s001

[7] Bootklad, M., & Kaewtatip, K. (2014). Biodegradability, mechanical, and thermal properties of thermoplastic starch/cuttlebone composites. *Polymer Composites*, *36* (8), 1401–1406. https://doi.org/10.1002/pc.23046

[8] Brevik, E. C., Khaledian, Y., & El-Ramady, H. (2021a). Assessing the complex links between soils and human health: An area of pressing need. *Frontiers in Soil Science*, *1*. https://doi.org/10.3389/fsoil.2021.731085

[9] Brevik, E. C., Khaledian, Y., & El-Ramady, H. (2021b). Assessing the complex links between soils and human health: An area of pressing need. *Frontiers in Soil Science*, *1*. https://doi.org/10.3389/fsoil.2021.731085

[10] Bulut, A., & Altunkaynak, Y. (2024). *Effective removal of ni (ii)ions from aqueous solutions using low-cost, eco-friendly natural and modified potato peels*. Research Square Platform LLC. https://doi.org/10.21203/rs.3.rs-4113388/v1

[11] Chaitow, L. (2004a). Strength plus endurance equals stability. In *Maintaining Body Balance, Flexibility and Stability* (pp. 133–161). Elsevier. https://doi.org/10.1016/b978-044307351-9.50009-8

[12] Chaitow, L. (2004b). Strength plus endurance equals stability. In *Maintaining Body Balance, Flexibility and Stability* (pp. 133–161). Elsevier. https://doi.org/10.1016/b978-044307351-9.50009-8

[13] Chen, L.-Y., Peng, J.-Y., Xu, J.-Q., Choi, H., & Li, X.-C. (2013). Achieving uniform distribution and dispersion of a high percentage of nanoparticles in metal matrix nanocomposites by solidification processing. *Scripta Materialia*, *69* (8), 634–637. https://doi.org/10.1016/j.scriptamat.2013.07.016

[14] Cisneros-Zevallos, L., & Akbulut, M. (2024). Reducing agricultural waste and losses with nanotechnology: Shifting paradigms in food safety, produce shelf life, and plant protection. *Journal of Agricultural and Food Chemistry*, *72* (29), 16045–16047. https://doi.org/10.1021/acs.jafc.4c05226

[15] Dang, C. (n.d.). *Examining the role of microbial communities in soil carbon cycling across levels of complexity* [West Virginia University Libraries]. Retrieved September 18, 2025, from https://doi.org/10.33915/etd.12641

[16] Ding, X. W., Hou, B. D., Xue, Y., & Jiang, G. H. (2017). Long-Term effects of ecological factors on nonpoint source pollution in the upper reach of the yangtze river. *Journal of Environmental Informatics*. https://doi.org/10.3808/jei.201700370

[17] Fairbrass, A., O'Sullivan, A., Campbell, J., & Ekins, P. (2023). *The SDG monitoring framework provides limited evidence that environmental policies are delivering multiple ecological and social benefits*. Wiley. https://doi.org/10.22541/essoar.167527462.20087822/v1

[18] Feng, T., Zhang, Y., & Wang, P. (2025). *Long-term effects of restoration strategies on ecosystem functions, soil conservation and afforestation on the Loess Plateau*. Copernicus GmbH. https://doi.org/10.5194/egusphere-egu24-9142

[19] Haleem, N., Osabutey, A., Albert, K., Zhang, C., Min, K., Anderson, G., & Yang, X. (2023). Flocculation of livestock wastewater using cationic starch prepared from potato peels. *Environmental Science: Water Research & Technology*, *9* (6), 1690–1700. https://doi.org/10.1039/d2ew00794k

[20] Halsband, C., & Booth, A. M. (2020). Ecological impacts of particulate plastics in marine ecosystems. In *Particulate Plastics in Terrestrial and Aquatic Environments* (pp. 231–246). CRC Press. https://doi.org/10.1201/9781003053071-18

[21] Izutsu, K., & Sato, H. (1992). Rapid backward movement of anaphase chromosome whose kinetochore fibers were cut by ultraviolet microbeam irradiation. *Biology of the Cell*, *76* (3), 339–350. https://doi.org/10.1016/0248-4900 (92)90437-6

[22] Jha, M., Sunaina, Arora, A., & Sood, K. (2023). Wastewater treatment using nanoadsorbents derived from waste materials. In *Waste to Profit* (pp. 147–164). CRC Press. https://doi.org/10.1201/9781003334415-11

[23] Li, M. (n.d.). *Effect of starch structure on the processing, mechanical properties and biodegradability of thermoplastic starch films* [University of Queensland Library]. Retrieved September 15, 2025, from https://doi.org/10.14264/uql.2015.280

[24] Lindenmayer, D., & McDonald, T. (2020). Large-scale, long-term ecosystem monitoring: Interview with David Lindenmayer. *Ecological Management & Restoration*, *21* (1), 26–34. https://doi.org/10.1111/emr.12400

[25] Liu, Y., Xie, H., & Shi, M. (2016). Effect of ethanol–water solution on the crystallization of short chain amylose from potato starch. *Starch - Stärke*, *68* (7–8), 683–690. https://doi.org/10.1002/star.201500300

[26] Lobanov Dmitriy, S., & Lunegova Ekaterina, M. (2023). Study of the thermal and moisture aging effect on the residual mechanical properties of a structural composite material. *Procedia Structural Integrity*, *50*, 163–169. https://doi.org/10.1016/j.prostr.2023.10.037

[27] Maiti, S. K. (2022). Ecological restoration of waste dump generated from an integrated steel plant: A case study. In *Innovative Exploration Methods for Minerals, Oil, Gas, and Groundwater for Sustainable Development* (pp. 157–171). Elsevier. https://doi.org/10.1016/b978-0-12-823998-8.00089-2

[28] Meléndez Rodríguez, B. (n.d.). *Development and characterization of monolayers and multilayers based on biodegradable materials derived from waste and by-products of interest in food packaging* [Universitat Politecnica de Valencia]. Retrieved September 15, 2025, from https://doi.org/10.4995/thesis/10251/184651

[29] *Methods of testing plastics. Mechanical properties*. (n.d.). https://doi.org/10.3403/00037491

[30] Molnar, M., & Marek, C. (2005, January 10). Simplified two -time step method for calculating combustion and emission rates of jet-a

and methane fuel with and without water injection. *43rd AIAA Aerospace Sciences Meeting and Exhibit*.
https://doi.org/10.2514/6.2005-549

[31] Naddeo, C., Guadagno, L., & Vittoria, V. (2004). Photooxidation of spherilene linear low-density polyethylene films subjected to environmental weathering. 1. Changes in mechanical properties. *Polymer Degradation and Stability*, *85* (3), 1009–1013.
https://doi.org/10.1016/j.polymdegradstab.2003.04.005

[32] Nesticò, A. (2022). Investments in the water and energy sectors. Cost–Benefit analysis and multi-criteria assessments to support the decision-making processes. In *Advances in Science, Technology & Innovation* (pp. 3–6). Springer International Publishing. https://doi.org/10.1007/978-3-031-00808-5_1

[33] Raafat, S., Abou-Zaid, M., Tohamy, M., & Arisha, H. (2016). Impact of some plant essential oil treatments on controlling cherry tomatoes spoilage, improvement shelf life and quality attributes during storage. *Zagazig Journal of Agricultural Research*, *43* (3), 785–813. https://doi.org/10.21608/zjar.2016.101014

[34] Rahmi, Hafiza, U., Febriani, & Julinawati. (2025). Influence of citric acid as crosslinking agent on the mechanical properties of chitosan-cellulose composite film. *IOP Conference Series: Earth and Environmental Science*, *1510* (1), 012059.
https://doi.org/10.1088/1755-1315/1510/1/012059

[35] Raza, Z. A., Siddque, A., & Mohsin, M. (2017). Multi-Performance enhancement of knitted wool fabric with citric acid: An eco-compatible cross-linker. *Journal of Natural Fibers*, *14* (6), 887–896. https://doi.org/10.1080/15440478.2017.1302383

[36] Ruelas-Monjardín, L. C. (2013). Water management in Mexico: Analysis from the sustainability perspective. In *WIT Transactions on State of the Art in Science and Engineering* (pp. 69–85). WIT Press. https://doi.org/10.2495/978-1-84564-756-8/005

[37] Schmitt, R. J. (2016). The long-term ecological research construct for understanding dynamics of coral reef ecosystems and its influence on my science. In *Long-Term Ecological Research*. Oxford University Press.
https://doi.org/10.1093/oso/9780199380213.003.0044

[38] Sica, M. (2021). It has never been more urgent to develop non-invasive outpatient care. *Acta Phlebologica*, *22* (2). https://doi.org/10.23736/s1593-232x.21.00504-x

[39] Singh, B.-, & Rengel, Z. (n.d.). The role of crop residues in improving soil fertility. In *Soil Biology* (pp. 183–214). Springer Berlin Heidelberg. Retrieved September 18, 2025, from https://doi.org/10.1007/978-3-540-68027-7_7

[40] Sotudeh-Gharebagh, R., & Chaouki, J. (2021). 1 Conventional scale-up method: Challenges and opportunities. In *Scale-Up Processes* (pp. 1–20). De Gruyter. https://doi.org/10.1515/9783110713985-001

[41] *Supplemental Information 4: Water column depths where water samples for Chl-a concentration and microbial community characterization microbiology were obtained*. (n.d.). https://doi.org/10.7717/peerj.13999/supp-4

[42] Takács, Á. (2019). Rules of environmentally friendly packaging. In *Solutions for Sustainable Development* (pp. 196–202). CRC Press. https://doi.org/10.1201/9780367824037-25

[43] Tao, Z. (2025). Correction to: Towards Sustainability: Exploring Sustainable Innovation in Chinese Agricultural Food Packaging. In *World Sustainability Series* (pp. C1–C1). Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-81469-3_15

[44] Thitiwongsawet, P., Saetan, S., & Siangsanoh, P. (2017). Properties of composite films from sugarcane bagasse, coconut coir, and water hyacinth fibers/poly (vinyl chloride). *Materials Science Forum*, *890*, 196–203.
https://doi.org/10.4028/www.scientific.net/msf.890.196

[45] Varžinskas, V., & Markevičiūtė, Z. (2020). Sustainable food packaging: Materials and waste management solutions. *Environmental Research, Engineering and Management*, *76* (3), 154–164. https://doi.org/10.5755/j01.erem.76.3.27511

[46] Weligama Thuppahige, V. T. (2025). *Characterization and performance analysis of cassava peel and bagasse as alternative, non-edible starch sources for biodegradable food packaging* [Queensland University of Technology]. Retrieved September 18, 2025, from https://doi.org/10.5204/thesis.eprints.233701

[47] Williams, H., & Wikström, F. (2022). *Plastic packaging has an evil twin*. Monash University. https://doi.org/10.54377/c96a-8c29

[48] Xiao, J., Xie, W.-Y., & Wang, P. (2025). Metagenomic insights into the ecological risks of multiple heavy metals on soil bacterial communities and resistance-related genes. *Ecotoxicology and Environmental Safety*, *303*, 119048.
https://doi.org/10.1016/j.ecoenv.2025.119048

[49] Xing, H., & Yang, L. (2025). Retention of fragmented fine woody debris enhances soil health, microbial activity, and ecosystem functions in urban forests of Northeast China. *Plant and Soil*. https://doi.org/10.1007/s11104-025-07576-3.

# Effect of Diverse Nutrient Sources and Liquid Organic Manures on Growth Parameters, Weed Count, Weed Dry Weight and Quality Parameters of Sesame (*Sesamum indicum* L.)

V. Tejaswi[1*]; A. Upendra Rao[2;] B. Jyothi Basu[3]; S. Govinda Rao[4]

[1,2,3]Department of Agronomy, Acharya N.G Ranga Agricultural University, Agricultural College, Naira
[4]Department of Statistics and Computer Applications, Acharya N.G Ranga Agricultural University, Agricultural College, Naira
*Corresponding Author: V. Tejaswi

Received:- 08 October 2025/ Revised:- 14 October 2025/ Accepted:- 23 October 2025/ Published: 31-10-2025
Copyright @ 2025 International Journal of Environmental and Agriculture Research
This is an Open-Access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (https://creativecommons.org/licenses/by-nc/4.0) which permits unrestricted Non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

***Abstract—*** *A field experiment was conducted to study "Organic nutrient management in rabi sesame (Sesamum indicum L.)" during 2024-25 at the Agricultural College Farm, Naira. The experiment was laid out in a split-plot design with three replications. The study consists of three main plot treatments viz., 100% RDN through inorganic fertilizers, 100% RDN through organics with biofertilizers and biofertilizers alone. The sub-plots included four foliar applications: Vermiwash, Panchgavya, Jeevamrut and water spray. The results showed that inorganic nutrient application (100% RDN) significantly improved growth, weed and quality parameters of sesame compared to organic and biofertilizer treatments. Among the foliar sprays, Jeevamrut @ 10% proved most effective, enhancing growth and quality parameters. The study concludes that applying 100% RDN through inorganic fertilizers combined with foliar spraying of Jeevamrut @ 10% is the most effective practice for enhancing growth, oil and protein content of sesame.*

***Keywords— Sesame, Jeevamrut, Panchgavya, Vermiwash, Biofertilizers and Organics.***

## I. INTRODUCTION

Sesame (*Sesamum indicum* L.), often referred as the "Queen of Oilseeds," is one of the oldest cultivated oilseed crops known for its high oil (50-52%) and protein (17-19%) content, along with carbohydrates and essential fatty acids (Kahyaoglu and Kaya, 2006). Sesame oil, popularly termed as "poor man's ghee," is highly nutritious and holds several health benefits. The seeds are rich in calcium, magnesium, zinc, antioxidants like sesamin and sesamol and vitamin E, which support heart health, digestion, skin and bone strength. Sesame is versatile in its use as it can be consumed raw, roasted or processed into oil, tahini and it can be used in cosmetics and ayurvedic medicine. In India, sesame is cultivated in an area of 15.31 lakh hectares with a production of 8.47 lakh tonnes and productivity of 553 kg $ha^{-1}$. However, in Andhra Pradesh, despite its significance, productivity remains low at 376 kg $ha^{-1}$ due to poor soil fertility, minimal inputs and suboptimal agronomic practices (Indiastat, 2023-2024). *Rabi* sesame, predominantly grown in the north coastal regions of Andhra Pradesh, often receives only one or two irrigations, making foliar nutrient application more practical than soil fertilization. The limited attention to crop nutrition has contributed to consistently low yields.

Conventional sesame farming relies heavily on synthetic fertilizers, which, though effective in the short term but adversely affect soil health, microbial diversity and the environment. As sesame is particularly sensitive to nutrient imbalances, sustainable alternatives are crucial. Organic nutrient management offers a promising approach by enhancing soil organic

matter, microbial activity and overall fertility while reducing environmental harm. Additionally, organically grown sesame is gaining international demand due to consumer preference for eco-friendly and chemical-free produce. Organic inputs like press mud cake, a byproduct rich in nutrients and organic matter, improve soil structure, water retention and microbial activity. Similarly, vermicompost is rich in plant growth regulators from microbial-earthworm interactions, has been shown to enhance plant growth, flowering and yields (Arancon and Edwards, 2009; Jayashree *et al.*, 2011). Biofertilizers, through phytohormone production and nutrient mobilization, further aid in plant development in an eco-friendly way. Foliar applications of liquid organic manures also play a critical role in boosting crop performance. *Jeevamrut*, *Panchgavya* and Vermiwash are effective natural formulations rich in nutrients, beneficial microbes and plant hormones. *Jeevamrut* improves nutrient availability and soil microbial activity, which boosts sesame growth and yield. Its application produces a healthy, biologically active rhizosphere that increases plant vigor, oil content and seed quality. *Panchgavya*, for instance, supplies key macro and micronutrients along with microbial inoculants like *Azotobacter* and phosphobacteria (Praneeth *et al.*, 2021), while vermiwash contains bioactive compounds and microbial enzymes that stimulate plant metabolism and nutrient uptake. In this context, integrating soil-applied organic and inorganic nutrient sources with foliar sprays of liquid organic manures may serve as an effective strategy to improve the growth, yield and profitability of *rabi* sesame, particularly under low-input conditions.

## II. MATERIAL AND METHODS

The present field experiment was conducted during *Rabi*, 2024-25, laid out in block- A, field No.6 of Agricultural College Farm, Naira, Acharya N.G. Ranga Agricultural University, Andhra Pradesh, which is geographically situated at 18.240° N latitude, 83.840° E longitude with an altitude of 27 m above mean sea level in the North Coastal Zone of Andhra Pradesh. The mean maximum and minimum temperatures ranged from 30.1°C to 37.8°C and 16.8°C to 25.6°C, respectively, while the average maximum and minimum temperatures during the crop period were 33.95°C and 14.3°C. During the corresponding period, the mean relative humidity of the forenoon is 82.88 per cent and the afternoon is 56.95 per cent, with an average of 69.91 per cent. A total rainfall of 19.8 mm was received in 2 rainy days during the crop growth period. Favorable weather conditions prevailed for the successful growth of the sesamum. The experiment was laid out in a split-plot design with three main plot treatments involving different nutrient sources: 100% RDN through inorganic fertilizers ($M_1$), 100% RDN through organics with biofertilizers ($M_2$) and biofertilizers alone ($M_3$). The sub-plots included four foliar applications: Vermiwash ($S_1$), *Panchgavya* ($S_2$), *Jeevamrut* ($S_3$) and water spray ($S_4$). Data was collected on various characters such as the plant population, leaf area index, dry matter production (kg $ha^{-1}$), days to 50% flowering, days to maturity, weed count, weed dry weight, oil content and protein content.

## III. RESULTS AND DISCUSSION

### 3.1 Growth Parameters:

#### 3.1.1 Plant population (No. $m^{-2}$):

The plant population of sesame observed at initial and final was unaffected by foliar applications of liquid organic manures and various nutrition sources, as well as their interaction effect. The uniformity in emergence may be due to uniform field preparation and sowing conditions across the plots. These observations are in line with the findings of Singh *et al.* (2024) and Kiruthika *et al.* (2022a), who reported that early plant stand in sesame remains unaffected by fertilizer type when seedbed preparation and irrigation are uniformly optimal.

#### 3.1.2 Leaf area index (LAI):

Application of 100% RDN through inorganic fertilizers ($M_1$) recorded the highest leaf area index (LAI) at both 30 and 50 DAS, primarily due to enhanced nitrogen availability that stimulated canopy expansion, efficient light interception, and higher

photosynthetic activity. These results are consistent with the findings of Kumar *et al.* (2022) and Pandiyan *et al.* (2020), who reported greater LAI in sesamum under recommended inorganic fertilizer levels. The treatment receiving 100% RDN through organics + biofertilizers ($M_2$) exhibited moderate LAI, indicating sufficient nutrient supply through gradual mineralization, in agreement with Singh *et al.* (2024) and Kiruthika *et al.* (2022a). The lowest LAI was observed in liquid biofertilizers alone ($M_3$), likely due to limited availability of essential nutrients restricting leaf expansion. Among foliar applications, *Jeevamrut* @ 10% ($S_3$) recorded the highest LAI, followed by Vermiwash @ 10% ($S_1$) and *Panchgavya* @ 3% ($S_2$), whereas water spray ($S_4$) consistently registered the lowest values. The superior performance of *Jeevamrut* could be attributed to its rich microbial population and growth-promoting substances that enhanced cell elongation and leaf development, corroborating Gabhane *et al.* (2019) and Prakash *et al.* (2019). The interaction effect between nutrient sources and foliar treatments on LAI at both stages was statistically nonsignificant.

### 3.1.3 Dry matter production (kg ha$^{-1}$)

Among nutrient sources, the highest dry matter accumulation was recorded under 100% RDN through inorganic fertilizers ($M_1$) at all growth stages (30 DAS, 50 DAS and harvest), attributed to the immediate availability of nutrients enhancing photosynthetic efficiency and biomass synthesis. Similar observations were reported by Kranthikumar *et al.* (2025) and Elayaraja Singaravel (2017). The treatment receiving 100% RDN through organics + biofertilizers ($M_2$) produced moderate dry matter, while biofertilizers alone ($M_3$) resulted in the lowest values, likely due to inadequate nutrient supply. Among foliar applications, *Jeevamrut* @ 10% ($S_3$) recorded the highest dry matter accumulation at all growth stages, followed by *Vermiwash* @ 10% ($S_1$) and *Panchgavya* @ 3% ($S_3$), whereas water spray ($S_4$) consistently registered the lowest. The superior performance of *Jeevamrut* could be attributed to its enrichment with beneficial microbes and growth-promoting metabolites that enhance nutrient uptake and metabolic activity, as supported by Veeral *et al.* (2019) and Ranjith *et al.* (2021).

The interaction between nutrient sources and foliar treatments was significant at 50 DAS and at harvest. The highest dry matter accumulation was obtained under $M_1S_3$ (inorganics + *Jeevamrut*) and among organic treatments, $M_2S_3$ (organics + *Jeevamrut*) produced the highest dry matter, reflecting the synergistic influence of microbial activity and gradual nutrient release from organics. The lowest dry matter accumulation was observed in $M_3S_4$ (biofertilizers + water spray), where insufficient nutrient availability restricted vegetative growth and final biomass production.

### 3.1.4 Days to 50% flowering:

Among the nutrient sources, soil application of liquid biofertilizers ($M_3$) recorded the earliest flowering, followed by 100% RDN through organics + biofertilizers ($M_2$). Conversely, the application of 100% RDN through inorganic fertilizers ($M_1$) took the longest time to reach 50% flowering. The early flowering observed under organic nutrition could be attributed to the moderate and steady nutrient availability through biofertilizers and organic amendments, which promote early physiological activity. Similar trends were reported by Ranjith *et al.* (2021), who observed early flowering in sesame under integrated nutrient management involving biofertilizers. Among foliar sprays, water spray ($S_4$) resulted in the earliest flowering, whereas *Jeevamrut* @ 10% ($S_3$) significantly delayed flowering, likely due to enhanced vegetative growth resulting from higher microbial and nutritional activity. The delayed flowering under *Jeevamrut* @ 10% ($S_3$) might also be due to its hormonal influence and enriched microbial community, which prolongs the vegetative phase. These results align with the findings of Deepak Bawa *et al.* (2024) and Veeral *et al.* (2019), who noted that foliar application of organic liquids delayed flowering while promoting extended vegetative growth. The interaction effect between nutrient sources and foliar sprays of liquid organic manures on days to 50% flowering was found to be non-significant.

**TABLE 1**

**INFLUENCE OF NUTRIENT SOURCES AND FOLIAR APPLICATION OF LIQUID ORGANIC MANURES ON GROWTH PARAMETERS OF SESAMUM**

| Treatments | Plant population (No. m-2) | | Leaf area index (LAI) | | Dry matter production (kg ha-1) | | | Days to 50% flowering | Days to maturity |
|---|---|---|---|---|---|---|---|---|---|
| | Initial | Final | 30 DAS | 50 DAS | 30 DAS | 50 DAS | At harvest | | |
| **Main plots: Sources of nutrition** | | | | | | | | | |
| $M_1$: 100% RDN through inorganic fertilizers | 35.56 | 31.93 | 0.35 | 3.09 | 402 | 1372 | 2824 | 36.41 | 82.16 |
| $M_2$: 100% RDN through organic (1/3rd each through Press Mud cake + Vermicompost + FYM) + liquid bio fertilizers (*Azospirillum*+ PSB + KRB @ 1.25 Lit $ha^{-1}$). | 35.3 | 32.18 | 0.23 | 2.37 | 300 | 1058 | 2371 | 31.41 | 76.91 |
| $M_3$: Soil application of liquid bio-fertilizers (*Azospirillum* + PSB + KRB @ 1.25 Lit $ha^{-1}$) | 33.19 | 30.77 | 0.14 | 1.52 | 257 | 774 | 1792 | 26.68 | 71.64 |
| S.Em± | 0.68 | 1.01 | 0.01 | 0.06 | 5.67 | 31.36 | 51.29 | 0.9 | 1.71 |
| CD (P=0.05) | NS | NS | 0.02 | 0.22 | 22.2 | 123.1 | 201.3 | 3.52 | 6.7 |
| CV (%) | 6.81 | 11.02 | 8.59 | 8.23 | 6.15 | 10.17 | 7.63 | 9.86 | 7.69 |
| **Sub plots: Foliar application of liquid organic manures** | | | | | | | | | |
| $S_1$: Vermiwash spraying twice @ 10% conc. at flower initiation and capsule development | 34.8 | 31.24 | 0.25 | 2.51 | 344 | 1109 | 2528 | 32.8 | 78.85 |
| $S_2$: *Panchgavya*spraying twice @ 3% conc. at flower initiation and capsule development | 34.16 | 32.01 | 0.23 | 2.22 | 314 | 1073 | 2380 | 30.93 | 76.43 |
| $S_3$: *Jeevamrut* spraying twice @ 10% conc. at flower initiation and capsule development | 33.91 | 32.91 | 0.27 | 2.84 | 411 | 1212 | 2631 | 36.27 | 80.85 |
| $S_4$: Water spray | 35.87 | 30.35 | 0.19 | 1.74 | 209 | 878 | 1776 | 26 | 71.48 |
| S.Em± | 0.97 | 1.08 | 0.01 | 0.06 | 9.9 | 27.31 | 50.46 | 1.14 | 2.21 |
| CD (P=0.05) | NS | NS | 0.03 | 0.19 | 29.4 | 81.14 | 149.9 | 3.39 | 6.56 |
| CV (%) | 8.37 | 10.27 | 11.18 | 8.25 | 9.3 | 7.67 | 6.5 | 10.86 | 8.61 |
| Interaction (M at S) | NS | NS | NS | NS | NS | 171.4 | 299.1 | NS | NS |
| Interaction (S at M) | NS | NS | NS | NS | NS | 140.5 | 259.7 | NS | NS |

**TABLE 1.1**

**INTERACTION EFFECT OF DIFFERENT SOURCES OF NUTRITION AND FOLIAR APPLICATION OF LIQUID ORGANIC MANURES ON DRY MATTER PRODUCTION (kg ha$^{-1}$) OF SESAME AT 50 DAS**

| Treatments | $S_1$ | $S_2$ | $S_3$ | $S_4$ | Mean |
|---|---|---|---|---|---|
| **$M_1$** | 1466 | 1457 | 1483 | 1082 | **1372** |
| **$M_2$** | 1007 | 1003 | 1225 | 999.1 | **1058** |
| **$M_3$** | 853.6 | 761.5 | 928 | 551.5 | **774** |
| **Mean** | **1109** | **1073** | **1212** | **878** | |
| | | **S.Em±** | **CD (P=0.05)** | **CV (%)** | |
| | | 31.35 | 123.1 | 10.16 | |
| | | 27.3 | 81.14 | 7.66 | |
| **INTERACTION** | | | | | |
| **M X S** | | 51.59 | 171.4 | - | |
| **S X M** | | 47.3 | 140.5 | - | |

**TABLE 1.2**

**INTERACTION EFFECT OF DIFFERENT SOURCES OF NUTRITION AND FOLIAR APPLICATION OF LIQUID ORGANIC MANURES ON DRY MATTER PRODUCTION (kg ha$^{-1}$) OF SESAME AT HARVEST**

| Treatments | $S_1$ | $S_2$ | $S_3$ | $S_4$ | Mean |
|---|---|---|---|---|---|
| **$M_1$** | 3132 | 2880 | 3159 | 2125 | **2824** |
| **$M_2$** | 2574 | 2543 | 2609 | 1759 | **2371** |
| **$M_3$** | 1910 | 1686 | 2126 | 1445 | **1792** |
| **Mean** | **2539** | **2369** | **2631** | **1776** | |
| | | **S.Em±** | **CD (P=0.05)** | **CV (%)** | |
| | | 51.28 | 201.3 | 7.62 | |
| | | 50.46 | 149.9 | 6.05 | |
| **INTERACTION** | | | | | |
| **M X S** | | 91.44 | 299.1 | - | |
| **S X M** | | 87.41 | 259.7 | - | |

### 3.1.5 Days to maturity:

Among the main treatments, soil application of liquid bio-fertilizers ($M_3$) resulted in the earliest maturity, followed by $M_2$ (organic sources + biofertilizers). The early physiological maturity in soil application of liquid bio-fertilizers ($M_3$) may be attributed to regulated, gradual nutrient supply and enhanced microbial activity, which stimulate faster reproductive development. Similar outcomes were documented by Mokariya *et al.* (2021), who found that biofertilizer-enriched vermicompost accelerated crop maturity through improved nutrient assimilation. Among the foliar treatments, water spray ($S_4$) matured the earliest, where as *Jeevamrut@* 10% ($S_3$) took the longest. The longer maturity period with *Jeevamrut* ($S_3$) could be attributed to prolonged vegetative growth aided by improved nutrient uptake and hormonal stimulation from organic foliar sprays, as suggested by Ranjith *et al.* (2021). The interaction effect of nutrient sources and foliar sprays on days to maturity was determined to be non-significant for days to maturity.

### 3.2 Weed Parameters:

### 3.2.1 Weed count (No. m$^{-2}$):

Among the nutrient sources, application of 100% RDN through inorganic fertilizers ($M_1$) resulted in the highest weed count at both 20 and 40 DAS, which could be attributed to increased nutrient availability that promoted the growth of both crops and weeds. Application of 100% RDN through organics + biofertilizers ($M_2$) showed a moderate weed count, whereas biofertilizers ($M_3$) alone recorded the lowest, likely due to reduced initial nutrient availability and improved crop shading during early establishment. Sukhadia *et al.* (2004) also observed that timely weeding at 20 and 40 DAS substantially reduced weed infestation. Among foliar sprays, *Jeevamrut* ($S_3$) recorded the highest weed count at both 20 and 40 DAS, possibly due to its stimulatory effect on overall soil microbial activity, which indirectly supported weed growth. Conversely, water spray ($S_4$)

recorded the lowest weed count, likely due to reduced crop vigour, which limited weed establishment. The interaction effect between nutrient sources and foliar applications of liquid organic manures on weed count at 20 and 40 DAS in sesame was found to be non-significant.

### 3.2.2 Weed dry weight (kg ha$^{-1}$):

Among the nutrient sources, application of 100% RDN through inorganic fertilizers ($M_1$) recorded the highest weed dry weight at both 20 and 40 DAS. The lowest weed dry weight was observed under soil application of liquid biofertilizers ($M_3$), indicating a suppressive effect on weed growth under low-nutrient input systems. Moderate weed biomass was recorded with 100% RDN through organics + biofertilizers ($M_2$), suggesting that gradual nutrient release from organic inputs influences early weed establishment differently than inorganic sources. These findings suggest that higher fertilizer inputs without weed control can enhance weed biomass, which aligns with the observations of Sahu *et al.* (2019) and Ismail *et al.* (2015), who reported greater weed proliferation under nutrient-rich conditions. Regarding foliar applications, *Jeevamrut* ($S_3$) recorded the highest weed dry weight at both 20 and 40 DAS, likely due to enhanced microbial activity and nutrient cycling that favored weed growth. It was followed by *Vermiwash* ($S_1$) and *Panchgavya* ($S_2$), whereas water spray ($S_4$) consistently recorded the lowest weed biomass, reflecting limited nutrient stimulation for weed development. The interaction effect between nutrient sources and foliar application of liquid organic manures on weed dry weight at 20 and 40 DAS was found to be non-significant.

**TABLE 2**

**INFLUENCE OF NUTRIENT SOURCES AND FOLIAR APPLICATION OF LIQUID ORGANIC MANURES ON WEED AND QUALITY PARAMETERS OF SESAMUM**

| Treatments | Weed count (No. m-2) | | Weed dry weight (kg ha-1) | | Oil content (%) | Protein content (%) |
|---|---|---|---|---|---|---|
| | 20 DAS | 40 DAS | 20 DAS | 40 DAS | | |
| $M_1$: 100% RDN through inorganic fertilizers | 5.37 (28.35) | 7.0 (48.56) | 7.59 (57.14) | 11.66 (135.4) | 48.79 | 20.69 |
| $M_2$: 100% RDN through organic (1/3rd each through Press Mud cake + Vermicompost + FYM) + liquid bio fertilizers (*Azospirillum*+ PSB + KRB @ 1.25 Lit ha$^{-1}$). | 4.60 (20.62) | 6.04 (36.03) | 6.60 (43.04) | 10.55 (110.7) | 47.64 | 19.42 |
| $M_3$: Soil application of liquid bio-fertilizers (*Azospirillum* + PSB + KRB @ 1.25 Lit ha$^{-1}$) | 4.04 (15.82) | 5.17 (26.28) | 5.65 (31.38) | 9.48 (89.32) | 44.15 | 17.93 |
| S.Em± | 0.74 | 0.67 | 1.2 | 3.73 | 0.82 | 0.37 |
| CD (P=0.05) | 2.92 | 2.63 | 4.72 | 14.66 | 3.23 | 1.44 |
| CV (%) | 11.93 | 6.28 | 9.5 | 11.56 | 6.09 | 6.59 |
| **Sub plots: Foliar application of liquid organic manures** | | | | | | |
| $S_1$: Vermiwash spraying twice @ 10% conc. at flower initiation and capsule development | 5.05 (25.01) | 6.46 (41.24) | 6.94 (47.71) | 11.07 (122) | 48.06 | 20.14 |
| $S_2$: *Panchgavya*spraying twice @ 3% conc. at flower initiation and capsule development | 4.78 (22.30) | 6.37 (40.06) | 6.85 (46.46) | 10.69 (113.8) | 47.49 | 18.86 |
| $S_3$: *Jeevamrut* spraying twice @ 10% conc. at flower initiation and capsule development | 5.34 (28.02) | 6.85 (46.36) | 7.35 (53.56) | 11.51 (132) | 48.76 | 22.36 |
| $S_4$: Water spray | 3.40 (11.05) | 4.55 (20.17) | 5.31 (27.70) | 8.95 (79.52) | 43.13 | 16.01 |
| S.Em± | 0.74 | 1.43 | 1.68 | 3.79 | 1.04 | 0.64 |
| CD (P=0.05) | 2.21 | 4.25 | 5 | 11.25 | 3.1 | 1.89 |
| CV (%) | 10.31 | 11.61 | 11.52 | 10.16 | 6.67 | 9.87 |
| Interaction (M at S) | NS | NS | NS | NS | NS | NS |
| Interaction (S at M) | NS | NS | NS | NS | NS | NS |

### 3.3 Quality Parameters:

#### 3.3.1 Oil content (%)

Among the nutrient sources, application of 100% RDN through inorganic fertilizers ($M_1$) recorded the highest oil content, while 100% RDN through organics + biofertilizers ($M_2$) was statistically on par with it. Both treatments were significantly superior to the soil application of liquid biofertilizers ($M_3$), which recorded the lowest oil content. The higher oil content under inorganic nutrition may be attributed to better nutrient availability and uptake, particularly nitrogen and potassium, which play crucial roles in oil biosynthesis in oilseed crops. Regarding foliar organic inputs, significant variations were observed. Foliar application of *Jeevamrut* @ 10% ($S_3$) at flower initiation and capsule development stages recorded the highest oil content and the lowest oil content was recorded under water spray ($S_4$). The improvement in oil content with organic foliar inputs might be due to the presence of microbial metabolites, growth-promoting substances and micronutrients in *Jeevamrut* and other organic formulations that enhance plant metabolism and oil accumulation in seeds. Similar observations were reported by Chakraborty *et al.* (2021). The interaction between soil and foliar treatments was statistically non-significant for oil content in sesame.

#### 3.3.2 Protein content (%):

Among the nutrition sources, application of 100% RDN through inorganic fertilizers ($M_1$) recorded the highest protein content, followed by 100% RDN through organics + biofertilizers ($M_2$) and soil application of liquid biofertilizers ($M_3$). The superiority of 100% RDN through inorganic fertilizers ($M_1$) could be due to the efficient availability of nitrogen in inorganic form, which plays a pivotal role in protein synthesis. These findings align with those of Shathi *et al*. (2023), who observed enhanced protein content in sesame under balanced chemical fertilization. Regarding foliar sprays, *Jeevamrut* @ 10% ($S_3$) once again recorded the highest protein content, followed by Vermiwash ($S_1$) and *Panchgavya* ($S_2$). The treatment water spray ($S_4$) recorded the lowest protein content. The higher protein content under *Jeevamrut* treatment may be due to the presence of amino acids, enzymes and beneficial microbes that facilitate nitrogen assimilation and protein formation in plants. The interaction effect between nutrient sources and foliar applications was statistically not significant for protein content.

## IV. CONCLUSION

The study revealed that 100% RDN through inorganic fertilizers significantly enhanced growth, biomass accumulation and seed quality of *rabi* sesame compared to organic and biofertilizer treatments. Among foliar applications, *Jeevamrut@* 10% was most effective in improving nutrient uptake, leaf development, oil and protein content and overall crop vigor. Organic sources with biofertilizers provided moderate benefits, while biofertilizers alone were least effective. The integration of inorganic fertilization with *Jeevamrut*foliar spray maximized sesame growth and quality, indicating its suitability as an efficient and sustainable nutrient management strategy.

## REFERENCES

[1] Arancon, N. Q and Edwards, C. A. 2009. The utilization of vermicomposts in horticulture and agriculture. In *Proceedings of Indo-US Workshop on Vermitechnology in Human Welfare.* (pp. 98-108).

[2] Chakraborty, P., Bairagya, M. D., Sarkar, S., Gulati, J. M. L., Santra, G. H., Nayak, N and Sahoo, B. K. 2021. Effects of Irrigation and Nutrient Management on Summer Sesame (*Sesamum indicum* L.). *International Journal of Current Microbiology and Applied Sciences*. 10(10): 212-220.

[3] Deepak Bawa, Amritpal Singh, Ritika and Kamalesh Kumar. Influence of integrated nutrient management on growth and quality of sesame (*Sesamum indicum* L.)under irrigated conditions. *International Journal of Research in Agronomy.*7(1): 446-449.

[4] Elayaraja, D and Singaravel, R. 2017. Effect of vermicompost and micronutrients fertilization on the growth, yield and nutrients uptake by sesame (*Sesamumindicum* L.) in coastal saline soil. *International Journal of Agricultural Sciences*. 13(2): 177-183.

[5] Gabhane, A. R., Gite, P. A., Khadse, V. A., Kadu, P. R and Patle, P. N. 2019. Production potential of organic summer sesame as influenced by compost, foliar nutrients and biofertilizers. *Journal of Pharmacognosy and Phytochemistry*. 8(2S): 47-50.

[6] Indiastat,2023.https://www.indiastat.com/table/agriculture/area-production-productivity- sesamum- india-1950-19/36611.

[7] Ismail, A. E. A., Sedeck, F. S and Ali, S. A. M. 2015.Influence of water regimes and weed control treatments on sesame crop. *Egyptian Journal of Agricultural Sciences*. 66(1): 40-53.

[8] Jayashree, S., Rathinamala, J and Lakshmanaperumalsamy, P. 2011. Determination of heavy metal removal efficiency of *Chrysopogonzizanioides* (Vetiver) using textile wastewater-contaminated soil. (2011): 543-551.

[9] Kahyaoglu T and Kaya S. 2006. Modelling of moisture, color and texture changes in sesame seeds during the conventional rusting. *Journal of Food and Engineering.* 75:167-177.

[10] Kiruthika, G., Poonkodi, P., Angayarkanni, A., Sundari, A and Sriramach and rasekharan, M. V. 2022a. Enhancing the Growth and Productivity of Sesame (*Sesamum Indicum* L.) Through different Organic Manures in Sandy Loam Soil. *Bull. Env. Pharmacol. Life Sci*. 11: 33-43.

[11] Kranthikumar, P., Ghotmukale, A. K., Sireesha, P., Khedkar, V. A and Sukne, S. S. 2025. Effect of foliar application of fertilizer on growth and seed yield of sesame (*Sesamum indicum* L.). *Plant Archives*. 25(1): 1513-1518.

[12] Kumar, K. C., Maitra, S., Shankar, T., Panda, M and Sagar, L. 2022. Growth and productivity of sesame (*Sesamum indicum* L.) as influenced by spacing and nitrogen levels. *Crop Research.* 57(3): 190-194.

[13] Mokariya, L. K., Vaja, R. P., Malam, K. V and Jani, C. P. 2021. Effect of microbial consortia enriched vermicompost on growth, yield and quality of summer sesame (*Sesamum indicum* L.). *Journal of Pharmaceutical Innovation*. 10(12): 974-977.

[14] Pandiyan, C. V., Bhlsji, K., Saravanan, S., Shylaja, G., Srinivasan, G. R., Saghana, P.R. K and Manivel, G. 2020. Effect of vermicompost application on soil and growth of the plant Sesamum indicum L. *Preprints.* (doi:10.20944/preprints202002. 0080.v1).

[15] Prakash, M., Narayanan, G. S., Anandan, R and Kumar, B. S. 2019. Effect of organic seed treatment and foliar spray on growth, yield and resultant seed quality in sesame (*Sesamum indicum* L.). *The Indian Society of Oilseeds Research*. 36(1): 30-35.

[16] Praneeth, M., Singh, R and Singh, E. 2021. Response of late sown wheat (*Triticum aestivum* L.) to organic and liquid manures on yield and economics. *The Pharma Innovation Journal.* 10(10):1488-1490.

[17] Ranjith, R., Meyyappan, M., Ganapathy, M and Ankayarkanni, A. 2021. Sesame yield improvement techniques. *Innovative Technologies and its Applications in Higher Education*. 252.

[18] Sahu, M. P., Jain, N., Bermaiya, U., Jain, V and Kumar, A. 2019. Enhancing productivity and profitability through herbicidal weed control in sesame. *Indian Journal of Weed Science.* 51(2): 214–216.

[19] Shathi, T. A., Syed, M and Rahman, M. K. 2023. Growth and quality characteristics of sesame (*Sesamum indicum* L.) as influenced by vermicompost and chemical fertilizers. *Journal of the Asiatic Society of Bangladesh Science*.49(1): 43-53.

[20] Singh, A., Kumar, D., Sah, D., Mishra, A and Gupta, A. K. 2024. Effect of Organic Manures on Soil Nutrients, Growth and Yield of Sesame (*Sesamum indicum* L.) in Bundelkhand Region of Uttar Pradesh. *Journal of the Indian Society of Soil Science*. 72(1): 126-130.

[21] Sukhadia, N. M., Ramani, B. B., Mathukia, R. K and Khanpara, V. D. 2004.Integrated weed management in kharif sesamum. *Indian Journal of Weed Science.* 36(3 and 4): 239-242.

[22] Veeral, D and Nayakanti, G. 2019. Effect of integrated organic nutrient management (INM) practices on plant architecture and yield of sesame (*Sesamum indicum* L.). *Crop Research.* 54 (5 and 6): 126-130.

# Promotion of Crop- Livestock Integration for Sustainable Resource Utilization

Arun Ninawe

Ex-Scientist, Department of Biotechnology, CGO Complex, Lodhi Road, New Delhi-110003

Received:- 09 October 2025/ Revised:- 16 October 2025/ Accepted:- 23 October 2025/ Published: 31-10-2025
Copyright @ 2025 International Journal of Environmental and Agriculture Research
This is an Open-Access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (https://creativecommons.org/licenses/by-nc/4.0) which permits unrestricted Non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

***Abstract—*** *The Indian economy has undergone structural changes over time with variation in agricultural growth and contribution to agricultural GDP. Although, self-sufficiency in food production achieved at the macro level it is still facing food deficiency in food production. The Green Revolution introduced in 1960s serves as a landmark example of agriculture's transformative role in India's economy. It was successful by introducing high-yielding variety (HYV) seeds, chemical fertilizers, and modern irrigation techniques, significantly increasing the agricultural output. This has not only alleviated the nation's dependency on food imports but also boosted rural incomes with technological interventions to revitalizing agriculture and food security. The conventional agriculture is known to cause soil and pasture degradation because it involves intensive tillage particularly due to intense practice lead to marginal productivity. As a solution farmers, intensify their activities by integrating components of crop and livestock to work more economically feasible and environmentally sound farming. The crop-livestock farming introduced enhanced livestock production with substantial increase of food from animal origin. The integrated farming revolutionized with integration of livestock, aquaculture, horticulture, agro industry and allied activities helped poor farmers to sustain their livelihood with increase farm inputs. Integrative approach that combines with traditional agricultural practices aimed to achieve long-term environmental and socioeconomic benefits with traditional practices of crop rotation, intercropping, organic fertilizers, and water conservation methods. This provides ecological resilience and cost-effectiveness, benefiting small-scale farmers by enhancing soil health, biodiversity and environmental sustainability. The introduction of modern practices such as precision agriculture, modified crops, application of digital tools, and efficient irrigation systems offers productivity and resource management in food security need promotion of traditional knowledge for sustainable agricultural development. The improved integrated crop-livestock system and mixed farming can guarantee farm resource utilization with minimal impact of intensive farming preserving the environment.*

***Keywords— Agricultural practices, Aquatic resources, Animal husbandry, Integrated and mixed cropping, Sustainable production, Way forward.***

## I. INTRODUCTION

Agricultural productivity is an important concern for tackling food security issues in India. India's total food grain production (2024-25) recorded a production of 353.96 LMT with wheat, maize, groundnut, soybean due to favorable monsoon and timely rainfall promoted healthy crop development(PIB, 2024). The farmer-centric policies enhanced agri-infrastructure contributed to the rise in crop production with use of innovative agricultural technologies. Agricultural productivity realizes increase output level crops, livestock, or allied products by utilizing inputs such as land, labour, capital, fertilizer, feed, and livestock. While resolving the environmental and social issues it is possible to achieve the goal of food security, poverty reduction, and rural development. The Food Security Mission launched by India is increasing food access for the growing masses with improved productivity, reduce waste and ensure food to poor for livelihood support and poverty reduction (Singh et al, 2015). India is unlocking the full potential of agriculture to ensure long-term food security addressing challenges through effective extension services. Policy frameworks that addresses the structural constraints, promote inclusive growth, and facilitate value chain expansion that can help India's agricultural sector fulfilling the economic potential. By integrating innovation, sustainability India can paving way for a future agriculture prosperity. Historically, Indian agriculture has been rooted in a rich tradition of

sustainable practices, including crop rotation, organic fertilization, and water-conserving techniques. These methods promoted ecological balance and supported biodiversity. The Green Revolution introduced in 1960s brought an intensive focus on high-yielding varieties, chemical fertilizers, and pesticides, which significantly increased food production.

During this period the policymakers focused on research, extension, input supply, credit, marketing, price support, and spread of technology. This adoption of a new agricultural strategy relied on high-yielding varieties of crops, focus on multiple cropping, package approach, modern farm practices, and spread of proper irrigation facilities. The HYV seeds could yield more than double the existing level which enabled the nation to become self-sufficient in food grains. As a result, in 1966 India imported 18000 tonnes of HYV seeds which were distributed in the highly irrigated areas of Punjab, Haryana, and Western UP. Total food grains harvest increased from 74 million tonnes in 1966-67 to 105 mt in 1971- 72. Output growth increased food grain supplies leading to a decline in food grain prices. India is giving emphasis on industrial agriculture being a high growing remunerative sector with the use of technology like precision farming and automation, a focus on agro-based industries such as food processing, textiles, and dairy, and its significant contribution to the country's exports and economy. The challenges to promote crop livestock synergies and interactions aimed to integrate crops and livestock effectively with careful land use and raise productivity of specific mixed crop- livestock systems to facilitate expansion of food production ultimately to safeguard the environment with efficient use of natural resources. The farming sector is also aware of ecological sustainability combining with economic viability with integration of livestock that improves agricultural productivity while reducing negative environmental impacts. The maintenance of an integrated crop livestock system is dependent on the availability of adequate nutrients to sustain animals and plants and to maintain soil fertility. The growing fodder legumes and using them as a supplement to crop residue is the most practical and cost-effective method for improving the nutritional value of crop residues. The traditional knowledge and experience by local farmers able to apply an integrated system relatively to adopt with traditional wisdom with modern sustainable practices in precision agriculture to restore ecological health while maintaining productivity. Adopting climate-resilient methods can help farmers adapt to erratic weather patterns, safeguarding livelihoods and promoting community well-being. A holistic approach, merging traditional and modern methods catalyze sustainable agricultural model that balances productivity with environmental stewardship. Several challenges are facing Indian agriculture, viz: climate change, erratic weather patterns, droughts, and floods affect crop yields and farmer livelihoods, water scarcity, inefficient irrigation systems and over-extraction of groundwater exacerbate water scarcity. The overuse of chemical fertilizers and poor farming practices reduce soil fertility and crop yields. Research inputs and farm based innovations provided solutions to the sustainable agricultural practices, promote organic farming, crop rotation, and agroforestry to enhance soil health and biodiversity. The focus on diversification from cereals to high-value crops like fruits, vegetables, and medicinal herbs to increase incomes and reduce environmental degradation. The soil health cards promotes sustainable soil management enhancing the natural farming practices addressing challenges in food security and economic growth. Sustainable agriculture encompasses a diverse array of agricultural approaches aimed at enhancing the long-term resilience, productivity, and ecological sustainability. The agricultural models developed creating synergy by using the waste from one system as a resource for the other, such as manure for crops and crop residues for animal feed. This integration enhances soil fertility, reduces reliance on chemical inputs, and offers diversified income streams, and increases farm resilience to market and climate fluctuation underpins biodiversity conservation, nutrient cycling enhancement, and the fortification of agro-ecosystems against environmental change (Wezel et al., 2009. Giller et al., 2011). The primary objectives of sustainable agriculture are conserving natural resources, reduce reliance on synthetic inputs, mitigating negative environmental impacts, and ensure the financial viability of farmers by achieving long-term benefits like improved soil health and resilience. Crop-livestock integration intensify farming integrating components of crop and livestock to diversify farm produce and exploitation of unutilized resources (Patel et al, 2015). The integrated system reduces erosion, increases crop yields, soil biological activity and nutrient recycling This ecological balance is possible because of healthy soil supports like water regulation, nutrient cycling, and carbon sequestration, making agriculture more sustainable ease in agricultural yields, ecosystem services. The sustainable agricultural methods enhance crop yields by fostering beneficial ecosystem services, such as pollination, biological pest control, and nutrient cycling, which support natural processes and reduce the need for external chemical inputs. Practices like biodiversity conservation, cover cropping, and reducing tillage improve soil health and create a more resilient, productive farming system. (Bommarco et al., 2013). Organic Farming methods maintain soil microbial populations engaged in nutrient cycling, while agroforestry systems can provide habitat for pollinators and other beneficial creatures (Pretty et al., 2006; Jose, 2009).

Integrated farming system has revolutionized conventional farming of livestock, aquaculture, horticulture, agro fish integration, livestock-fish livestock integration or combinations of crop, livestock, fish and other enterprises. Thus integrated system offers benefits such as improved soil health and nutrient recycling, increased food production and income diversification, and enhanced resilience to climate change by minimizing reliance on external inputs (Olele et al. 1999). The system help poor small farmers, who on and a few heads of livestock to diversify farm production, increase cash income, improve quality and food production by exploitation of unutilized resources. Crops provide animals with fodder from grass, leguminous forages and crop residues and takes advantage of the animals on the farm to improve the environment in which crop production takes place. The animals provide draught power in crop production where the practice of animal traction is popular and their dung used as manure to improve soil fertility on crop fields. In crop-livestock integrated farming reduces erosion, increases crop yields, soil biological activity and nutrient recycling, intensifies land use understood to exist where both livestock and crop production take place within the same locality that put forward to improve sustainable productivity (Chan, 2006). The system help production, increase cash income, improve quality and integrated farming systems the most visible feature is the synergy between crops and livestock. Crop rotation and intercropping are adequately addressed for soil fertility and animal husbandry enhance soil health by increasing organic matter, improving nitrogen cycling, and promoting soil biodiversity enhancing the agricultural yields with augmented fertilizer availability and water use efficiency. In sub-Saharan Africa study indicates that maize yields increased by an average of 53% when cultivated in agroforestry systems compared to typical monoculture systems improving farmers' livelihoods through sustainable agriculture practices with better market access (Sileshi et al., 2008).

## II. METHODOLOGY

Extensive reviews were made to understand the farming system practiced in India and globally, covering prehistoric to the present day agriculture. The culture and the cropping systems adopted to suit different climatic conditions studied. Strategy suggested for adoption of farming pattern in the irrigation pattern for agriculture and allied integrated activities. The sustainability and productivity issues studied to address various challenges in farming system. The schemes and programs beneficial to farming community suggested with emphasis on introduction of new crops, technological innovations, farm management and crop diversity in agro-climatic zones for enhancing the production and sustainability. Information gathered on data classification and grouping ecological aspects, natural resource management, organic fertilizers and biodiversity issues highlighted. Qualitative descriptive methods suggested to understand the comprehensive and holistic approach in sustainable farming practices. Literature Selection relevant to research topic, data reliability and subject related journals, books, research reports were referred. The descriptive and diagnostic methodology explored to examines essential concepts and contexts in depth. The study emphasizes reliable secondary sources, encompassing a wide range of published and unpublished materials, such as academic literature, expert reports, books, journals, specialized media, websites, public records, and scholarly articles. Data is systematically organized and presented to fulfill significant insights, conclusions.

## III. SUSTAINABLE FARMING SYSTEMS: COMPONENTS AND PRACTICES

### 3.1 Agro-climatic Zones of India and Farming Suitability:

India’s agricultural scenario depends largely on agroclimatic conditions, which include factors like climate, soil type, rainfall, temperature, and topography. Different crops require different temperatures and rainfall patterns to sustain different farming systems. An integrated farming systems is a judicious mix and positive interaction between two or more components such as horticulture crops, livestock, aquaculture, poultry/ducks, apiculture, and mushroom cultivation. It uses with the principles of minimizing competition and maximize complementarity with advanced agronomic management tools. This environmentally friendly farm income, family nutrition supports ecosystem services. It also based on the objectives to minimize the waste from various subsystems of the farm by expanding the symbiotic or synergistic systems between livestock, aquaculture, agriculture, and agroindustry. The waste of one process becomes the input for other operations in India. In All India Coordinated Research Project (AICRP-ICAR) on IFS network has been established on various IFS models in 15 agro-climatic regions covering 23 states and 2 UTs. The rice grows well in hot and humid regions, while wheat needs cooler climates. Rainfall and irrigation are crucial for crop success with less rainfall depend heavily on irrigation. The plains are more suitable for extensive farming, while hilly regions support terrace and plantation agriculture. The Government of India’s Planning Commission giving emphasis on the utilization of long-term resource efficiency and sustainability in agriculture based on the soil’s topography

(Planning Commission of India, 1989, Table 1 & Figure 1}. The Indian Council of agricultural Research (ICAR) has redefined the resources and differentiated them on crops based patterns considering soil health, topography, rainfall, and temperature. The identified zones are used for scientific research and agricultural development in India. (Rohit Pradhan, 2014, Shubhdeep Mandal and Muthu Gogoi, 2022)**.**

**TABLE 1**
**DIFFERENT AGRO-CLIMATIC REGIONS/ZONES**

| Zone No. | Agro-climatic regions/zones | States represented | New Region |
|---|---|---|---|
| 1 | Western Himalayan region | Uttarakhand, Himachal Pradesh, Jammu and Kashmir | A |
| 2 | Eastern Himalayan region | Assam, Arunachal Pradesh, Manipur, | B |
| | | Meghalaya, Nagaland, Mizoram, Sikkim, | |
| | | Tripura and West Bengal | |
| 3 | Lower Gangetic plain region | West Bengal | C |
| 4 | Middle Gangetic plain region | Bihar, Uttar Pradesh | |
| 5 | Upper Gangetic plain region | Uttar Pradesh | |
| 6 | Trans Gangetic plain region | Delhi, Haryana, Punjab, Chandigarh, Rajasthan | |
| 7 | Eastern plateau and hills region | Orissa, west Bengal, Chhattisgarh, Jharkhand, Madhya Pradesh, Maharashtra | D |
| 8 | Central plateau and hills region | Madhya Pradesh, Uttar Pradesh, Rajasthan, | |
| 9 | Western plateau and hills region | Madhya Pradesh, Maharashtra | E |
| 10 | Southern plateau and hills region | Karnataka, Tamil Nadu. Andhra Pradesh, Telangana | |
| 11 | East coast plains and hills region | Pondicherry, Tamil Nadu, Orissa, Andhra Pradesh | F |
| 12 | West coast plains and hills region | Goa, Karnataka, Kerala, Maharashtra, Tamil Nadu | G |
| 13 | Gujarat plains and hills region | Gujarat, Rajasthan, Dadra& Nagar Haveli, Daman & Diu | H |
| 14 | Western dry region | Rajasthan | I |
| 15 | Island region | Andaman & Nicobar, Lakshadweep | Not used |
| Source: Planning Commission of India(Khanna, 1989) | | | |

### 3.2 Conceptual Framework: Integrated vs. Mixed Farming:

Integrated farming involves a holistic approach to farming, where different components of the farm are interconnected and interdependent. The major difference between integrated farming and mixed farming lies in their approach and scope. Integrated farming involves a comprehensive approach that combines different agricultural enterprises, such as crops, livestock, and fisheries, into a single farming aims to optimize resource use, minimize waste, and promote ecological balance. Mixed farming involves growing multiple crops and/or raising multiple types of livestock on the same farm. In this system different components of the farm may not be necessarily interconnected or interdependent. The primary of both the farming system are to focus on creating a sustainable farming that minimizes waste and optimize resource utilization. It offers numerous benefits, including integrating crops, livestock, and fisheries and farmers maximize resource efficient use of resources like land, water, and nutrients. It supports crop rotation, organic compost, and agroforestry enhance soil fertility and structure, reducing soil

erosion and nutrient losses. By combining multiple agricultural activities, farmers can generate income from various sources, such as crops, livestock, fish, and other value-added products, reducing their dependence on a single commodity market and sustainable because the waste of one enterprise becomes the input of another, leaving no waste to pollute the environment or to degrade the resource base. Thus crop livestock integration becomes effective and highly productive for achieving waste recycling range of resource-saving practices that aim to achieve acceptable profits and high and sustained production levels (Thornton and Herrero, 2001). The integrated system reduces soil erosion, increases crop yields, biological activity and nutrient recycling with effective land use thereby reduce poverty and malnutrition by strengthen environmental sustainability (Antonio and Silvia, 2010). The leftover crop residues provide fodder for livestock (Van Raay and Leeuw, 1971, Alhassan et al, 1983) while, grain provides supplementary feed for productive animals. The natural ecological conditions as characterized by ample sun, good soils and the absence of temperate extreme making favorable to both crop and livestock production provide suitable climatic condition to sustain farming in the highlands that supports the crop , fodder and animal production are high compared with the other system(Jahake, 1992).

### 3.2.1 Mixed Farming:

Mixed farming systems are livestock based systems in which more than 10% of the dry matter fed to animals comes from crop by-products such as stubble, or where more than 10% of the total value of production comes from non-livestock farming activities(Steinfeld et al, 2006) The manure is used as fertilizer; animals are used for draught and transport. Crop residues are used as livestock feed and animals can be sold and the revenues generated re- invested in agriculture during crop failure due to bad weather conditions and disease and pests. Mixed farming involves growing multiple crops and/or raising multiple types of livestock on the same farm with primary focus on diversifying agricultural production to reduce dependence on a single crop or livestock (Patel et al . 2015). The numerous benefits are offered by increased productivity efficiently utilizing resources leading to higher crop yields and livestock production. It enhances soil health and reducing reliance on chemical fertilizers and provides farmers with multiple revenue streams, reducing dependence on a single crop or livestock. This farming practice promotes ecological balance, conserves water, and reduces environmental degradation. Some successful examples of mixed farming in India include crop-livestock integration. The integrated crops includes wheat, rice, and pulses with dairy farming and poultry. Fishery and paddy cultivation under mixed farming with cultivation of wheat and maize together and raising cattle and poultry on the same farm maximize resource utilization. In many African countries, farmers practice mixed cropping to promote soil fertility to reduce pests and diseases. In Kenya, farmers grow maize, beans, and potatoes together. Mixed cropping is a common practice in Southeast Asia and India where farmers plant multiple crops at the same time to reduce the risk of total crop failure and make better use of soil nutrients. In the Philippines and Indonesia. It includes rice, maize, and soybeans, while in India, farmers in states like Maharashtra, Madhya Pradesh, and Uttar Pradesh grow wheat, gram, and mustard together. The cereal crops wheat and rye are grown with cattle, sheep, pigs, fish and poultry by adopting farming practices. This method is also known as intercropping when crops are grown in a specific, alternating pattern in rows of one crop followed by the row of another (Mustapha et al, 2021). Cultivation of mixed and rotational cropping can help mitigate climate change by sequestering carbon, reducing greenhouse gas emissions supporting the soil health. The adopted cultivation of crops alongside with rearing of animals for meat, eggs or milk in commercial farming making major investments using advanced technologies. Animal husbandry paid attention by addressing health care issues, cattle breeding, and the veterinary services. Intensive focus on feeding of dairy animals given for better milk yield and high income (Neeraj Kumar, 2024). Comparative productivity and economies of dairy enterprises (mixed farming with three crossbred cows on one hectare of canal irrigated land versus mixed farming with three Murrah buffalo) indicated that mixed farming with crossbred cows under canal-irrigated conditions were more efficiently utilization of land, capital, inputs and the labour resources of the farmer (Kumar et al, 1994). In Gujarat around 75 percent of rural households kept cattle in the face of under-employment, particularly, the cattle kept mainly for milk, contributed 32 per cent and 20 per cent by tribal and non-tribal ethnic groups respectively (Patil and Udo, 1997). The farm animals could also provide gainful resources such as crop residue that can be utilized in integrated system. The waste products of one component serve as a resource for the other. For example, manure is used to enhance crop production; crop residues and by-products feed to the animals, supplementing often inadequate feed supplies, thus contributing to improved animal nutrition and productivity (Ven Keulen and Schiere, 2004. Manyong et al, 2006). The overall benefits of crop-livestock integration keep maintenance of the soil productivity capacity, product diversification and higher yields and quality at less cost. The livestock can be fed on crop residues and other products that would otherwise pose a major waste disposal problem overcome by feeding straw, damaged fruits, grains and household wastes (Fakoya, 2002). Adverse climatic dynamics in recent years have intensified the need for resilient and multifunctional agricultural systems that integrate productivity, ecological sustainability, and socio-economic viability. (Anna Wenda-Piesik and Agnieszka Synowiec, 2021).

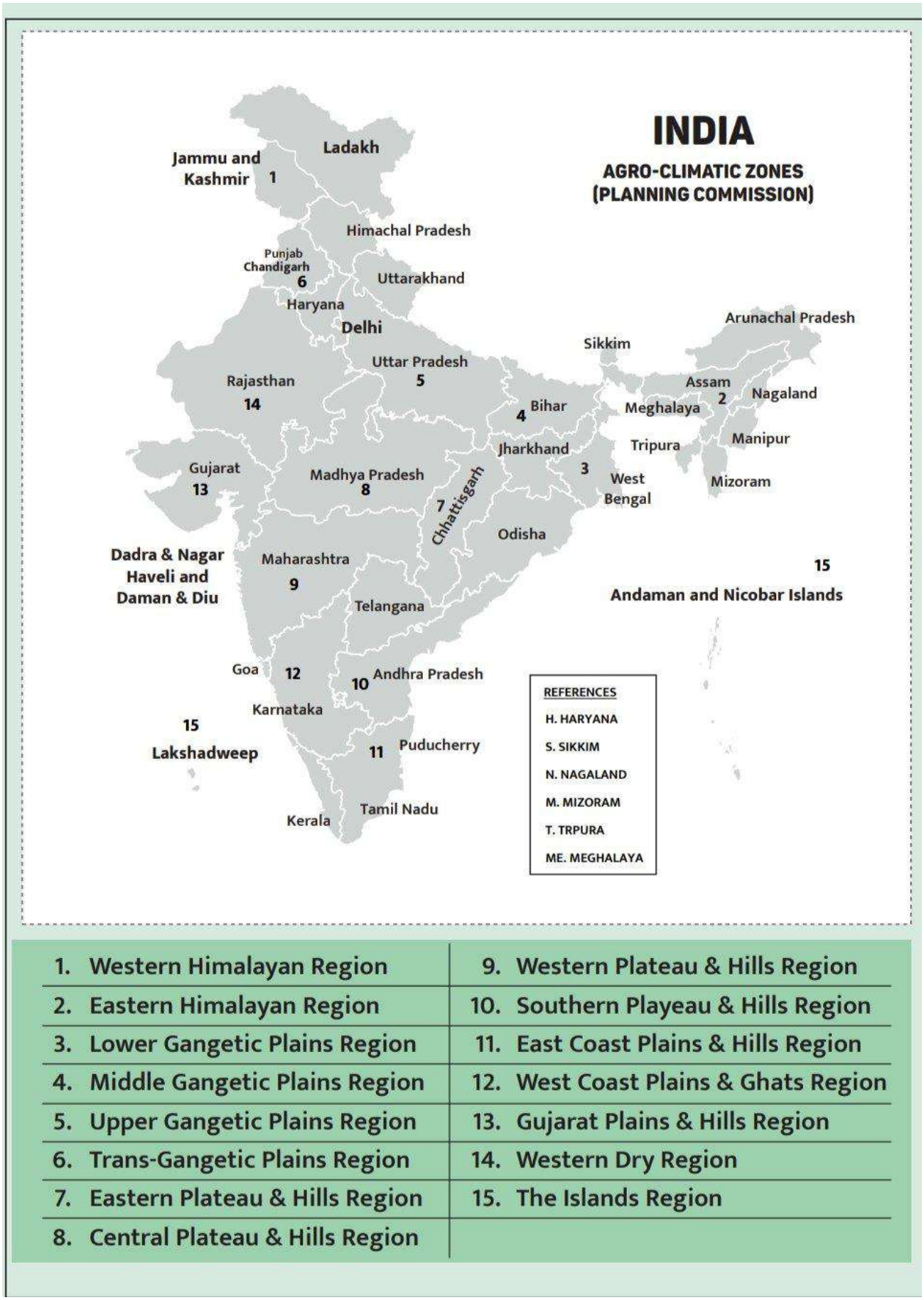



**FIGURE 1: Agro-climatic zones in Indian States (Khanna 1989)**

### 3.3 Integration of Aquatic Resources and Aquaculture

India is blessed with vast aquatic resources, promote sustainable development in the fisheries and aquaculture sector. The sector provides food, employment and prosperity of the people. The vast resources provides huge scope for expansion of aquaculture for the production of finfish and shellfish. The fisheries resources are given below in Table 2.

**TABLE 2**
**THE FISHERIES RESOURCES**

| **Marine resources and statistics**. |
|---|
| India's Coastline ---8118 km. |
| Exclusive Economic zone---2.02 million km2 |
| The Continental shelf---0.42 million km2 |
| The Fish landing Centers ---1376 |
| Fishing villages---3322 |
| Fishermen Families, as per NMFC, 2005)---764868 |
| Fisher Folk Population(No.)as per NFMC,2005---3574704 |
| **Inland Resources:** |
| Rivers and Canals---195210 km. |
| Reservoirs----31.5 lakh Ha |
| Tanks and Ponds 24.14 lakh Ha. |
| Flood Plains/derelict water bodies---8-12 Lakh Ha |
| Brackishwater ---12.40 lakh Ha. |
| Saline /alkaline affected area---12.00 lakh Ha. |

***Source: Report of the Working Group on fisheries, Planning Commission, 2011, Government of India.***

Fisheries provides food, employment and prosperity to the people. The vast area of water resources available in the country provides huge scope for expansion of aquaculture contributes to the national income, exports, food as well as employment generation both in inland and coastal areas. India stand 2nd in fish production with its 8 percent growth share in the global fish productivity and recorded high production of 17.45 MT production in 2023-24(Agro Spectrum, 2023). The Ministry of Fisheries, Animal Husbandry and Dairying is giving major focus on development of fisheries in India for adoption of modern fishing practices, expansion of aquaculture activities, and promotion of fish seed production and technology transfer. The scheme also emphasizes the conservation and sustainable activities to increase fish production, increasing the income of fisher folk. (Ghosh et al., 2019. Patro et al., 2021, Sarkar et al., 2020).

### 3.4 Advancements in Animal Husbandry Practices:

A combining livestock and crop production system increase income, improve quality and quantity of food with exploitation of unutilized resources. Integration of livestock and crop nutrients allow recycling more effectively to improve livestock productivity, reduce poverty, and increase farmers' income and conserve and develop indigenous cattle breeds, improve their productivity, and promote their use in agriculture. Artificial insemination improved cattle productivity and transferring embryos from high-quality donor cows to recipient cows help increase the genetic quality of cattle. ETT with increase productivity by transferring embryos from high-yielding donor cows, reduced risk of disease transmission between donor and recipient cows. In India artificial insemination (AI) in buffalo and cows widely adopted by injecting semen from high-quality bulls into cows or buffalo to improve their reproductive performance. Operation Flood mission launched in the 1970s, used AI to improve cattle productivity and increase milk production in India. National Dairy Development Board (NDDB) has implemented AI programs across India, improving cattle breed The application of embryo transfer technology (ETT) helped improvement of cattle and buffaloes with good quality breeds and success rate to demonstrate the commercial production of farm animals for higher milk productivity (Misra et.al, 2005). The population increase of crossbreds with artificial insemination program increases the profitability of the farmers and the dairy industry (Rajesh Wakchure et al. 2015). The technologies such as artificial insemination, frozen semen production, progeny-testing validated to fillip the gap of animal genetic conservation and preservation of germplasm. The Indian cattle Zebu, a cross bred of Indian Gir breed and the Holstein breed, known for its high milk production for their distinctive hump, large ears, and heat tolerance yielded better results. The breed is resistant to diseases and parasites, making them well-suited for tropical climates. India's milk production touched a target of 230.58 MT in 2023-24, makes India the World's largest milk producer country, accounting for more than 25 percentage of the world's milk production The Gir cow is the highest milk producing cow breed in India, yielding 50–80 liters of milk per day recognized

for high yield production and adaptability to different climates, with resistance to diseases and parasites. The Central Institute for Research on Buffaloes (CIRB) under ICAR in Hisar has improved the Murrah buffalo breed and for disseminating its semen to farmers and buffalo for fertilization of cows. This breed found most suitable breed in dairy production. The genetic studies and non-genetic factors studies influences the performance traits in lactation, milk yield dry period, birth weight, calf mortality, calving interval per conception and conception rate making effective breeding program with better performance traits. (Sarkar et.al, 2005).

### 3.4.1 Coordinated Research projects and Rural Bio resources Complexes:

Intensification of agriculture is currently occurring in most of the farming systems favors crop– livestock integration. An All India Coordinated Research Project (AICRP) is multi-institutional, multi-disciplinary research initiative that connects with various research centers and experts across the country to address specific agricultural or national priorities. These long-term projects, primarily supported by the Indian Council of Agricultural Research (ICAR), focus on developing and disseminating region-specific technologies to improve crop yields, animal husbandry, and other vital sectors for the benefit of farmers and the country. AICRP a network of centers, including the State Agricultural Universities (SAUs) and ICAR institutes collectively conduct collaborative research on farm based activities. Projects bring together specialists from different disciplines to achieve targeted outputs addressed to specific agricultural commodities viz; maize, pulses, small millets, or post-harvest technologies to test and develop region-specific technologies and disseminate to farmers to enhance production utilizing resource optimization different agro-climatic zones. Improved tailored made high-impact technologies in various regions and specific needs and supports adoption of indigenous emerging technologies for sustainable crop–livestock integration.

Rural Bio-Resource Complex Project was conceptualized during 2004 supported by DBT at UAS Bangalore with interdisciplinary approach scientists with a view to realize sustainable development in agricultural system. The project was implemented in Tubagere Hobli of Bangalore rural district covering 8340 farming and non- farming families spread over in 75 villages with a goal to enhance income and standard of living of farmers, access to quality inputs and custom hire services of agricultural machineries, provide functional linkage with various institutions working in rural area, market empowerment and the establishment of producers/ commodity based associations. The RBRC project implemented series of capacity building programs implemented for various stakeholders especially farmers through education and training. The results are highly encouraging fulfilling farm production efficiently through empowering farmers by upgrading their knowledge and skill. Empowerment on various facets of agricultural activities right from choice of crops to consumer preference is essential to farmers to enable them to reap the benefit from farm activities with technology adoption, carrying out timely farm operations and other activities like information on markets, transportation of farm to strengthen especially small and marginal farmers with better remunerative prices to their produce (Vinay Kumar et al, 2015).

### 3.5 The Role of Organic and Natural Farming:

Organic farming plays a significant role in supplementing integrated farming systems by providing a framework of sustainable and eco-friendly practices that enhance the overall production system. Adoption of organic methods reduce reliance on chemical inputs, improve soil health through nutrient recycling, and minimize environmental pollution, by encouraging farmers to adopt natural farming and practice chemical-free agricultural practice integrate with local livestock and diverse cropping systems. It emphasizes sustainability, biodiversity, and the health of ecosystems using compost and organic fertilizers, enhance soil structure, fertility, and microbial activity. These practices improve the soil's ability to retain moisture and nutrients, leading to increased agricultural productivity. (Yoganandham, 2024). Organic farming minimizes soil erosion and degradation. By avoiding chemical inputs that degrade soil structure and organic practices maintain the integrity of the soil ecosystem. By encouraging biodiversity, organic farms create habitats for various species, including beneficial insects, birds, and soil organisms and is the essential element for pollination, pest control, and the overall resilience of the agricultural system. The absence of synthetic chemicals means that organic farms contribute less to water pollution, preserving the health of rivers, lakes, and wetland, thus fostering soil health and promoting ecosystem balance. While embracing organic farming practices, there is need to study harmonious relationship between agriculture and nature, ensuring the well-being of both the environment and human health. The Ministry of Agriculture & Farmers' Welfare initiated to encourage farmers to adopt natural farming, a chemical-free agricultural practice that integrates local livestock and diverse cropping systems. The goal is to promote sustainable farming practices that provide safe, nutritious food for all, reduce input costs and dependence on externally purchased inputs. The NMNF scientifically revive agricultural practices, promoting sustainability, climate resilience, and healthy food both for farmers and consumers. The scheme is implemented in 15,000 clusters in Gram Panchayats reaching hundred million farmers by introducing natural farming over 7.5 lakh hectares and model demonstration farms established at

Krishi Vigyan Kendras (KVKs), Agricultural Universities (AUs), and farmers' fields. (Kumar et al, 2024. The mission disseminated further to develop synergies, and establish market linkages through local markets ultimately to promote entrepreneurship in natural farming practices. Krishi Vigyan Kendra (Farm Science Centre) is an innovative institution of ICAR established at district level. The first KVK was established during 1974 and has grown as a largest network in the country with 631 KVKs during 2012. KVKs are funded by ICAR and administered by ICAR institutes / SAUs /Deemed Universities / Non-government Organizations or State Department of Agriculture. KVKs play a supportive role in the larger agricultural extension system.

## IV. INSTITUTIONAL, RESEARCH, AND POLICY SUPPORT

### 4.1 National Research Initiatives (AICRP, RBRC)

Indias agriculture and allied sectors contributed approximately 16% of the national GDP with 46 % workforce employed in agriculture. The sector underpins rural livelihoods and drives the development of allied industries such as dairy, poultry, and fisheries. The prosperity in agriculture is directly linked to enhanced rural infrastructure, better income levels, and improved quality of life in villages. India launched New Agricultural Policy in 2000 aimed to achieve an output growth rate of 4 percent per annum in the agriculture sector on the basis of efficient use of resources in a sustainable manner and to strengthen rural infrastructure along with increasing employment opportunities in rural areas which will, in turn, improve the standard of living and check migration from the rural areas. NAP also supports economic liberalization by fulfilling the needs of the domestic and foreign markets with the process of diversification in non-food grains output like milk, fishery, poultry, vegetables, fruits. The sector significantly supports India's foreign trade, contributing $50 billion to exports in 2022-23, or approximately 13% of the country's total export by cultivation of high-value crops like fruits, vegetables, and spices, which enhance food security, improve nutrition levels, and provide opportunities for income diversification. It also provides raw materials for various industries, such as textiles, food processing, and pharmaceuticals promoting sustainable agriculture practices and improving farmer's livelihoods ensuring fair prices and promoting sustainable agriculture practices (Astha Banka et al. 2021).

### 4.2 Capacity Building and Extension Services

Capacity building is strengthening capabilities to perform their work more efficiently by the individuals to improve the efficiency by equipping the individuals to improve efficiency independently. Strengthening of institutions for promoting integrated farming system is essential for country like India with tailored based approach that addresses the challenges and opportunities in farming and extension services. Various approaches in capacity building of farmers are farmer's field schools, participatory technology development, on farm demonstrations, use of ICT, working through groups, distance education etc. available with institutional arrangements like KVKs, SAUs, and ICAR institutions (Durgesh Kumar Dubey. 2015). The Food and Agriculture Organization (FAO) is giving emphasis on strengthening agricultural institutions in developing countries to promote integrated farming with technical support, facilitate research, and coordinate with relevant stakeholders. The International Fund for Agricultural Development. (IFAD) supports training and extension activities for smallholder farmers in developing countries through workshops, training programs, and demonstration effectively to benefit farmers in integrated farming. The Farmer-to-Farmer Knowledge Exchange Programs disseminates in adoption of integrated farming systems by farmers in developing countries with sustainable agriculture development. The United Nations Development Programme (UNDP) supports policy frameworks with incentives to create an enabling environment for farmers to adopt integrated approaches. Emphasis on digital technologies platforms is given by World Bank to disseminate agricultural information giving access to information empowering the farmers in remote areas with knowledge empowerment. By implementing these strategies in a developing country fostering adoption of integrated farming practices, leading to increased agricultural productivity, improved sustainability and enhanced livelihoods.

### 4.3 National Missions and Policy Frameworks:

The Agriculture Development Strategy to 2025 and Vision 2030, strategic document projected the multifaceted approach to ensure the food security, produce comparative and competitive agricultural commodities, develop clean, safe and sustainable agriculture and shift agriculture gradually with modernization of technology. The government is addressing the need of farmers for food, income, and livelihood by emphasis on utilization of natural resource for better health and environment, employment generation with an aim achieve UN Sustainable Development Agenda 2030 (Niti Aayog, India, 2023). Fulfilling the vision, PM KISAN Yojana launched to support small and marginal farmers with allocation of budget introducing subsidies for food, fertilizers, and petroleum. The domestic agricultural marketing policies framed to create a fair and efficient marketing system to bring reforms, create market access to farmers for their produce (Acharya, 2001). NABARD (National Bank for Agriculture

and Rural Development), ICAR, APMC (Agricultural Market Produce Market Committee), and Food Corporation of India giving emphasis on Institutional Financing, Cooperative farming and bringing awareness for doubling farmer income with awakened lowering subsidies on seed and fertilizers The crop insurance program brings multiple stakeholders into a single window through PMFBY. The Kisan Call Centre, Agri Market App, and Kisan Suvidha App with digitalization, also introduced subsidies to meet the cost of agriculture for drone purchase and farm machineries. National Food Security Mission (NFSM) enhancing agricultural and food grains to improve the availability of essential food grains in the country. The emphasis is given soil and water management and soil health for sustainable and inclusive growth in food grain production. NFSM program has yielded positive and significant impact on increasing the production and productivity of rice, wheat and pulses, thereby helping in nutritional security of the masses. The performance was evaluated and the impact of NFSM on agricultural productivity, food security, and farmer welfare issues were examined (Kumar and Singh. 2017, Kumar and Jha, 2020).

## V. DISCUSSION AND WAY FORWARD

India is giving focus on sustainable integrated farming systems with improved extension services for farmers, scientists and stakeholders to improve the productivity efficiency for adoption in rural communities. While doing so it enhances agricultural productivity by addressing the pressing environmental concerns, including soil degradation, water scarcity, and biodiversity losses. It revives the traditional farming techniques, such as crop rotation, agroforestry, and organic farming, complements with modern practices like precision agriculture in agricultural system to sustain ecologically harmonious agricultural future. From this review it is concluded that the integrated farming system (IFS) is a promising enterprise for the marginal and small farmers by sustainable utilization of resources particularly who has less farm holdings. The study suggested to provide progressive economic growth, employment opportunities, family nutritional requirements, optimal utilization of available resources of the farming enterprises. Further many researchers found many types of integrated farming system models existing in the country but it has not properly documented to reach the mass farmers. Hence measures needed to document such kinds of farming system models to needy farmers. Although the integrated farming system has certain constraints the scientific community and research station has to initiate steps to alleviate such problems of the farmers to improve their standard of living and income.

## VI. CONCLUSION

Sustainable agriculture require strategies to mitigate the impact of climate change on agriculture, including crop management, irrigation systems, and soil conservation. The highly improved integrated livestock system ensure the interest of poor small farmers thereby increase the productivity of traditional farming systems by adopting an effective biomass while conserving the natural resources. India has taken major initiatives to excel the economic growth, job creation, and agricultural development with the initiatives launched by the government and by promoting organic farming with emphasis on horticulture of fruits, vegetables, and flowers. The animal husbandry, dairy and fisheries sector given scaling up integrated farming system in India and other developing countries. The potential for expanding integrated agricultural systems in India is by strengthening education and training that can bring awareness with enhancement of farmer's capacity. The research on sustainable agricultural practices can fosters innovation and sustainability with the schemes like crop insurance, crop protection and crop losses due to natural calamities. These are well addressed issues in agriculture and allied sectors with promotion of advanced farming technologies and introduction of organic farming. The policy initiatives taken by government fostering supportive frameworks and enhancing institutions by ensuring equitable access to capital inputs and markets and promotion of new commodities with sustainable resource utilization.

## VII. CONFLICT OF INTEREST

Author declares that there is no conflict of interest.

## VIII. ACKNOWLEDGEMENTS

The author acknowledges to all the Indian government departments for gathering the data, publications of Google research scholars' manuscripts including various other statistical reports, websites information for preparing the manuscript.

Orcid iD- https://orcid.org/0000-0001-9925-1069

## REFERENCES

[1] Acharya, S.S., (2001). Domestic Agricultural Marketing Policies, Incentives and Integration. In S.S. Acharya and D.P. Chaudhri. Indian Agricultural Policy at the Crossroads: Priorities and Agenda. Rawat Publications, Jaipur and New Delhi.

[2] Agro spectrum. 2023. India's Fish production at Record 175.45 Lakh Tonnes in 2023. Aquaculture, Agripolicy, Live Stock/ December 15, 2023.

[3] Alhassan W.S., Ehoche O.W., Adu I.F. and Obilana A.T. (1983). Crop residue potential of agricultural development projects, Chemical composition of crop residues, NAPRI Annual Report, Shika, Zaria, Nigeria.

[4] Anna Wenda-Piesik andAgnieszka Synowiec. (2021). Productive and Ecological Aspects of Mixed Cropping System. Agriculture, 11(5): 395. https://doi.org/10.3390/agriculture11050395

[5] Antonio R. and Silvia S. (2010) Integrated crop- livestock farming systems. International fund for agricultural development via paolo di dono, Rome, Italy

[6] Astha Banka, Amartya Singh, Aarushi Malhotra, Karthik Ramesh, Jai Gajjar and Anubhav Gupta(2021) Indian Agriculture Since Independence. International Journal of Research in Engineering, Science and Management. Vol ( 9): 251-254. https://www.ijresm.com | ISSN (Online): 2581-5792

[7] Bommarco R, Kleijn D, Potts SG (2013) Ecological intensification: harnessing ecosystem services for food security. Trends Ecol Evol 28:230–238. https://doi.org/10.1016/j.tree.2012.10.012

[8] Chan G L. 2006. Integrated farming system. What does integrated farming system do? http://www. scizerinm.org/chanarticle.htm.

[9] DOA & FW. (2024). Department of Agriculture and Farmers Welfare, Government of India. india.gov.in/ministry-agriculture-farmers-welfare.

[10] Durgesh Kumar Dubey. (2015). Capacity Building by Education and Training in Agriculture Sector: A Solution to Food Security in India (Pp. 97-105). National Conference on Implementation of National Food Security Act – 2013 organized by Pragati College of Arts & Commerce, Dombivli on 16-17 January, 2015. ISBN: 978-93-5202-385-1

[11] Fakoya E.O. (2002) Assessment of livestock production systems based on crop residues and legumes in humid zones of Nigeria. Proceeding of the Nigeria society for animal production 27th annual NASP conference, Akure. Pp. 374-376.

[12] Ghosh A, Datta A, Singh RS. (2019). Impact of blue revolution on fish production and livelihood of fishermen: A study of Purba and Paschim Medinipur Districts, West Bengal. Indian Journal of Agricultural Economics. 74(4):555565.

[13] Ken E. Giller, Marc Corbeels , Justice Nyamangara , Bernard Triomphe,Francois Affholder, Eric Scopel, Pablo Tittonell.(2011). A research agenda to explore the role of conservation agriculture in African smallholder farming systems. Field Crops Research. Vol 124( 3): 468-472

[14] Jahake H.E. (1992) Livestock production systems and livestock development in tropical Africa, Kieler Wiscenchaftsverlag Vauk. Pp. 72-74.

[15] Jose S (2009) Agroforestry for ecosystem services and environmental benefits: an overview. Agrofor Syst 76:1–10. https://doi.org/10.1007/s10457-009-9229-7

[16] Khanna, (1989). Agro-climatic regional planning: an overview (unpublished). Planning Commission, New Delhi, Pp. 144.

[17] Kumar A. and Jha GK.(2020).National Food Security Mission (NFSM) in India: Performance, challenges, and policy implications. Economic and political weekly. 55(45):24-32.

[18] Kumar H., Singh J.N., Kadian V.S., Singh K.P., Saxena K.K. and Kumar H. (1994). Farming Systems, 10: 36-44.

[19] Kumar S and Singh P.(2017). Impact assessment of National Food Security Mission (NFSM) on rice, wheat, and pulses production in India. Indian Journal of Agricultural Economics. 72(2):211-223.

[20] Kumar, Prince, Y. K. Singh, and Pankaj Kumar Ojha. (2024). Effectiveness of Different Extension Methods Used by KVKs Beneficiaries. Asian Journal of Agricultural Extension, Economics & Sociology 42 (10):281-90.
https://doi.org/10.9734/ajaees/2024/v42i102583.

[21] Manyong V.M., Okike I. and Williams T.O. (2006).Effective dimensionality and factors affecting crop-livestock integration in West African savannas. Agricultural Economics, 35(2): 145-155.

[22] Ministry of agriculture and farmers welfare, Government of India. (n.d.). National Food Security Mission (NFSM). Available:http://www.nfsm.gov.in/]

[23] Misra, A.K., S. Prasad and V.K. Taneja (2005). Embryo transfer technology (ETT) in cattle and buffalo in India: A review. The Indian Journal of Animal Sciences, 75(7): 842-857.

[24] ml.

[25] Mustapha Aliyu; Dada Ibilewa; Caleb Odiji.(2021). Mixed Cropping: Food Security Solution for Developing Countries. International Journal of Research and Innovation in Applied Science (IJRIAS) | Volume VI (II), February 2021|ISSN 2454-6194

[26] Neeraj Kumar., Tejendra Kumar and Madan Pal.(2024). Role of mixed farming for doubling farm's income (Chapter. 7, Pp. 77-83, In Book: Role of farming for doubling farm's income. Indian Publication.

[27] Niti Aayog, India. (2023)., From green revolution to Amrit Kaal- Lessions and Way Forward for Indian Agriculture (Eds. Ramesh Chand and Jaspal Singh). National Institution for Transforming India. Government of India, New Delhi, July 2023:1-44.

[28] Olele N.F., Nweke F.U. and Agbogidi, O.M. (1999). Role of Integrated Farming System in Agricultural Development in the Delta Region of Nigeria. Delta Agric, 6:128-134.

[29] Patel A. S., Patel S.J., Patel, N.R. AND G.M.,Chaudhary. (2015). Integrated Farming of Crop. International Journal of Agriculture Sciences. Vol 7(12): 777-781.

[30] Patil B.R. and Udo H.M.J. (1997). The impact of crossbred cows in mixed farming systems in Gujarat, India: milk production and feeding practices. .Asian-Australasian Journal of Animal Sciences,10: 253-259.

[31] Patro D, Pradhan BK, Mishra S. (2021). Blue revolution and its impact on aquaculture development in Odisha. Indian Journal of Fisheries. 68(1):17-21.

[32] PIB (2025) Ministry of Agriculture and Farmers' Welfare releases Third Advance Estimates of Production of major agricultural crops for 2024-25. Government of India, New Delhi.

[33] Pretty, J. (2006) Agroecological Approaches to Agricultural Development. Background paper for the world development report-2008.

[34] Rajesh Wakchaure, Subha Ganguly, Parveez Ahmad Para, Praveen Kumar Praveen, Avinash Kumar, Subhash Sharma.(2015). Development of Crossbred Cattle in India: A Review Associate, International Journal of Emerging Technology and Advanced Engineering Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 5, And Issue 10.

[35] Report of the Working Group on Fisheries, Planning Commission, 2011 for the 12th Five-Year Plan (2012-2017). Department of Fisheries, Government of India or the Ministry of Agriculture and Farmers Welfare, New Delhi.

[36] Rohit Pradhan, Sheshakumar Goroshi, Raghavendra P. Singh. (2014). Spatial and seasonal characterization of terrestrial biospheric carbon flux over India using GOSAT data, The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XL-8, 2014 ISPRS Technical Commission VIII Symposium, 09 – 12 December 2014, Hyderabad, India.

[37] Sarkar, A, Raha S., Bhattacharya, R. (2020). Challenges and prospects of blue revolution in India. Indian Journal of Economics and Development. 16(3): 429-436.

[38] Sarkar, U, A.K. Gupta, P. Yadav, T. K. Mohanty and V.S. Raina (2005). J. Dairying, Foods & H.S. 24(2):113-115.

[39] Sileshi, G., Akinnifesi, F. K., Ajayi, O. C., & Place, F. (2008). Meta-analysis of maize yield response to woody and herbaceous legumes in Sub-Saharan Africa. Plant and Soil, 307(1–2): 1–19.

[40] Singh, K.P., Singh S.N., Kumar H., Kadian V.S. and Saxena K.K. 1993. Economic analysis of different farming systems followed on small and marginal land holdings in Haryana. Haryana Journal of Agronomy, 9: 122-125.

[41] Singh, K.M., S. Sangeeta Kumari and Nasim Ahmed. (2015). Strengthening food security through agricultural productivity in India. Productivity. Vol. 65(3):262- 271.

[42] Steinfeld H., Gerber P., Wassenaar T., Castel V., Rosales M. and Haan C.D. (2006). Livestock's long shadow: environmental issues and options. Rev. Sci. Tech. Off. Int. Epiz., 25(2): 505-516.

[43] Subhadeep Mandal and Muthu Gogoi.(2022). Eastern Himalayan Division: A potential zone to the hub of agriculture. Indian Farmer, Vol. 9(12): 559-566.

[44] Thornton, P.K. and M. Herrero. (2001). Integrated crop-livestock simulation models for scenario analysis and impact assessment. Journal Agricultural Systems, Vol. 70 :581-602

[45] VanKeulen H. and Schiere H. (2004) Crop-livestock systems: Old wine in new bottles? In new directions for a diverse planet. Proceedings of the 4th International crop science congress, Brisbane, Australia.
http://www.cropscience.org.au/icsc2004/symposia/2/1/211_vankeulenh.ht

[46] Vinay Kumar R, K. Narayana Gauda, M. S. Nataraju and T. N. Anand. (2015). Impact of Rural Bio-Resource Complex Project on Standard of Living of its Stakeholders in Karnataka Mysore. J. Agric. Sci., 49 (3): 536-541.

[47] Wezel, A., Bellon, S., Doré, T. et al.2009. Agroecology as a science, a movement and a practice. A review. Agron. Sustain. Dev. 29, 503–515. https://doi.org/10.1051/agro/2009004

[48] Yoganandham, G. (2024). A Theoretical assessment of sustainable agriculture advancements in India: Integrated traditional and modern practices for environmental and socio-economic gains. GIS Science journal Vol. 11(10): 547-567.

# Soil-Plant Nutrient Dynamics and Fertilizer Use Efficiency in Maize & Desmodium Cropping System

Irine Akinyi Odera[1*]; Abigael Nekesa Otinga[2]; Ruth Njoroge[3]; Scholastica Mutua[4]

University of Eldoret, School of Agriculture and Biotechnology, Department of Soil Science
*Corresponding Author

Received:- 10 October 2025/ Revised:- 16 October 2025/ Accepted:- 25 October 2025/ Published: 31-10-2025
Copyright @ 2025 International Journal of Environmental and Agriculture Research
This is an Open-Access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (https://creativecommons.org/licenses/by-nc/4.0) which permits unrestricted Non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

***Abstract—*** *Soil fertility decline and inefficient nutrient use remain major challenges limiting maize productivity in the arid and semi-arid lands (ASALs) of Kenya. This study evaluated the effects of integrating farmyard manure (FYM) with inorganic fertilizers on soil properties, nutrient uptake, yield performance, and efficiency indices in sole maize sole desmodium and maize-desmodium intercrop systems under field conditions in Keiyo North. The experiment consisted of six fertilizer substitution ratios (0-0, 25-75, 50-50, 75-25, 100-0, and 0-100% farmyard manure-inorganic N equivalence) arranged in a randomized complete block design with four replications. Soil chemical parameters ($NH_4^+$, $NO_3^-$, pH, N, P, and C), plant nutrient uptake, and agronomic and recovery efficiencies were assessed. Results showed that combined farmyard manure – inorganic treatments, particularly 25-75 and 75-25, significantly improved soil nutrient status, enhanced N and P uptake, and increased maize and desmodium yields compared to sole applications. Farmyard manure -rich combinations improved moisture retention and microbial activity, sustaining nutrient release, while inorganic fertilizers ensured rapid early growth. Intercropping enhanced biological nitrogen fixation and nutrient recovery, leading to higher agronomic efficiency and resilience under moisture-limited conditions. The findings underscore that partial substitution of inorganic fertilizers with farmyard manure, coupled with maize-desmodium intercropping, offers a sustainable pathway to enhance soil fertility, nutrient use efficiency, and productivity in arid and semi-arid lands farming systems.*

***Keywords— Farmyard manure, nutrient use efficiency, soil fertility, ASALs.***

## I. INTRODUCTION

Declining soil fertility remains a major constraint to agricultural productivity in sub-Saharan Africa (SSA), largely due to continuous cropping, minimal nutrient replenishment, and poor fertilizer management practices (Ntinyari & Gweyi-Onyango, 2021). Excessive, improper, and unbalanced fertilizer use, particularly of nitrogen (N), has raised concerns over environmental degradation and soil health deterioration. Efficient nutrient management, particularly of nitrogen (N) and phosphorus (P), is therefore crucial to improving crop yield and sustaining soil productivity. The 4R principle, which entails applying the right source **(**fertilizer with higher efficiency**),** right rate**,** right time**,** and right placement, is recommended to enhance fertilizer use efficiency and reduce nutrient losses (Hochmuth et al., 2014). Proper placement and timing improve nutrient uptake by roots, minimizing leaching and gaseous losses. A promising strategy to further enhance efficiency is reducing nitrification through the use of nitrification inhibitors**,** which slow the microbial conversion of ammonium ($NH_4^+$) to nitrate ($NO_3^-$), thereby reducing $N_2O$ emissions and nitrate leaching (Coskun et al., 2017).

While chemical nitrogen fertilizers have significantly increased crop yields globally, their long-term excessive use has led to adverse effects, including soil acidification, ammonia volatilization, non-point source pollution, and elevated nitrous oxide emissions (Hu et al., 2023). Similarly, phosphorus fertilizers**,** such as triple superphosphate (TSP), play an essential role in root development, energy transfer, and nucleic acid synthesis. However, phosphorus is relatively immobile in soils and prone to fixation, particularly in iron and aluminum-rich soils such as Ferralsols and Nitisols. This fixation renders phosphorus unavailable to plants, necessitating higher application rates that can, in turn, cause eutrophication of water bodies when excessive P is lost through runoff. Therefore, ensuring P is applied at the right time and in forms that minimize fixation is

essential. Studies show that balanced fertilization combining organic and inorganic sources enhances P availability and utilization, resulting in improved yields and reduced environmental impacts (Ntinyari & Gweyi-Onyango, 2021).

Organic materials such as farmyard manure (FYM) supply all the major nutrients (N, P, K, Ca, Mg, S) and essential micronutrients (Fe, Mn, Cu, Zn), acting as a comprehensive nutrient source. FYM application improves soil structure, enhances water holding capacity, stimulates microbial activity, and supports long-term soil fertility. Furthermore, FYM contributes to soil organic carbon (SOC) buildup, which enhances soil resilience, nutrient retention, and carbon sequestration potential. The combined application of FYM and mineral fertilizers has been shown to enhance soil fertility, reduce nitrogen losses, and increase crop productivity (Hu et al., 2023). For instance, (Zeyede et al., 2020) reported that combining manure with chemical fertilizers improved SOC by 2.45%, enhancing nutrient cycling and microbial activity. Although total organic carbon (TOC) changes slowly, labile organic carbon fractions, such as microbial biomass carbon (MBC), dissolved organic carbon (DOC), particulate organic carbon (POC), and easily oxidized organic carbon (EOC), respond rapidly to management interventions, serving as indicators of soil health (Z. Zhang et al., 2021).

Maize (*Zea mays*) is a staple crop in sub-Saharan Africa (SSA), where it accounts for up to 30% of the calorie intake of the population (Taylor & Tanumihardjo et al., 2010). Maize is also the most widely cultivated crop in the region, grown in 46 out of 53 countries in SSA (Abate et al., 2017). Despite the expansion in area under maize production, by 30.2% between 2007 and 2017, yield gains have been modest at only 8.5% (*FAOSTAT*, 2020). In Kenya, nitrogen and phosphorus deficiencies remain the most critical limitations to maize productivity (J. Kihara et al., 2016). High fertilizer costs and limited access (Nziguheba et al., 2016) have driven many smallholder farmers to rely on crop residues and manure to supply nutrients. However, these inputs often contain insufficient N and P to sustain high maize yields.

To address these challenges, intercropping maize with legumes has emerged as a promising strategy to improve soil fertility and productivity. Legume-based intercropping enhances nutrient cycling through biological nitrogen fixation**,** contributes organic matter, improves soil structure, and promotes more efficient resource use (Ndayisaba et al., 2021). Legumes can also increase phosphorus availability through the release of root exudates and organic acids that mobilize bound P, improving nutrient access for both crops in the intercrop.

Among potential intercrops, *Desmodium* (*Desmodium silverleaf*) stands out as a highly beneficial legume. It is a perennial, nitrogen-fixing forage crop known for its deep rooting system, high biomass production, and ability to improve soil fertility. *Desmodium* forms symbiotic associations with rhizobia to fix atmospheric nitrogen, enriching soil nitrogen pools. In addition, it exudes allelopathic compounds that suppress weeds like *Striga hermonthica* while enhancing phosphorus solubilization through organic acid secretion. These attributes make *Desmodium* an ideal intercrop with maize, improving overall nutrient efficiency, soil health, and system sustainability.

Efficient nutrient utilization is key to sustainable agricultural intensification. Nutrient use efficiency (NUE) reflects how effectively plants absorb and use applied nutrients for growth and yield. High NUE minimizes nutrient losses to the environment, while low NUE often results in nutrient accumulation in soils, leading to potential greenhouse gas emissions and environmental degradation. Optimizing NUE through balanced organic–inorganic fertilization is therefore critical for achieving sustainable yield gains while minimizing environmental footprints. This study aimed to: (i) Assess the impact of different organic–inorganic fertilizer combinations on soil chemical and physical properties in Keiyo North. (ii) Evaluate the nutrient use efficiency of maize and Desmodium under various fertilizer substitution ratios.

## II. MATERIALS AND METHODS

### 2.1 Study Area:

This was an on-farm study conducted in Keiyo North sub-county of Elgeyo Marakwet County. The county is situated in Kenya's Rift Valley and covers an area of 3,029.6 km², representing 0.4 % of Kenya's total land area. It stretches from latitude 0° 20′ to 1° 30′ north and longitude 35° 0′ to 35° 45′ east. The county is mainly characterized by mixed crop, livestock, and agro-pastoral production systems, with key food crops including maize, beans, and green grams. The primary livestock enterprises are cattle (both dairy and beef), goats, sheep, and poultry (County Government of Elgeyo Marakwet, 2018). The area is situated at an altitude of 2804 Meters above sea level. Its climate varies from cool in the highlands, mild on the escarpment, too hot in the lowlands, with an annual mean temperature of 20.47 °C and rainfall of 127 mm spread over two rainy seasons. Figure 1 displays the map of the study site.

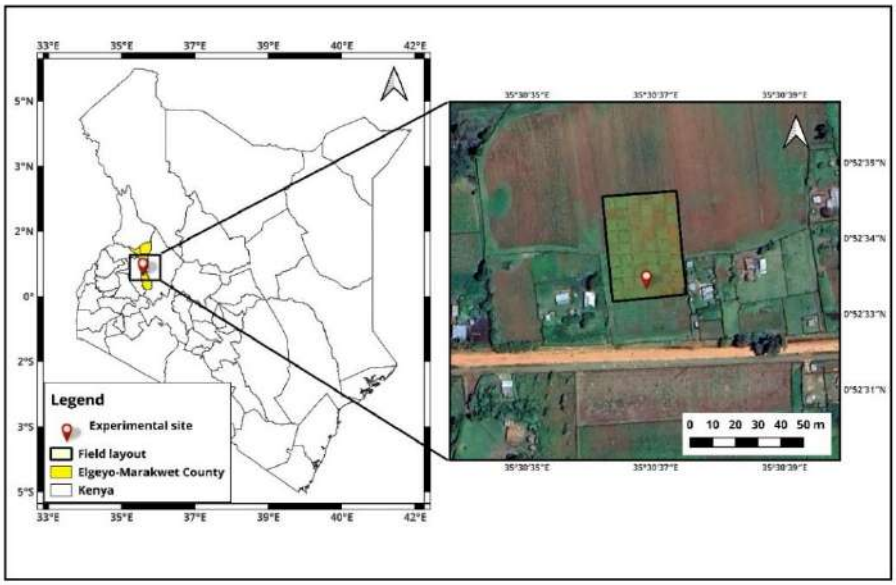



**FIGURE 1: Map showing the location of the study site in Keiyo North in Elgeyo Marakwet County, Kenya**

### 2.2 Experimental Setup:

The experiment was initiated in April 2024. The trial was laid out in a factorial experiment in Randomized Complete Block Design, with different Farmyard manure FYM and inorganic fertilizers substitution rates, under three cropping systems, namely, sole maize, sole *desmodium*, and maize-*desmodium* intercrop. The six fertilizer substitution rates were: (i) 0 FYM and 0 Inorganic – No fertilizer (Control); (ii) 25 75 - 25% of 30kg Pha-1 supplied by FYM, and 75% of 30kg Pha-1 supplied by Inorganic fertilizer; (iii) 50 50 - 50% of 30kg Pha-1 supplied by FYM and 50% of 30kg Pha-1 supplied by Inorganic fertilizer; (iv) 75 25 -75% of 30kg Pha-1 supplied by FYM, and 25 % of 30kg Pha-1 supplied by Inorganic fertilizer; (v) 100 0 - 100% of 30kg Pha-1 supplied by FYM and 0% of 30kg Pha-1 supplied by Inorganic fertilizer; and 0 100 - 0% of 30kg Pha-1 supplied by FYM and 100% of 30kg Pha-1 supplied by Inorganic fertilizer. Fertilizer application rates in this experiment were calculated based on the phosphorus (P) requirement to avoid oversupplying other nutrients, particularly potassium (K) and nitrogen (N). When N was used as the basis for calculation, it resulted in excessive application of both P and K due to the fixed nutrient ratios in the manure fertilizer blends. This would have exceeded the intended target rates of 100 kg N $ha^{-1}$, 30 kg P $ha^{-1}$, and 60 kg K $ha^{-1}$. We applied Farmyard manure (FYM), Urea, Triple Superphosphate (TSP), and Muriate of potash (MOP). The plots measured 5m by 4.5 m, and the whole experimental plot will be 61 m by 32.5 m. The maize variety planted was H6213 with a spacing of 75 cm inter-row and 25 cm intra-row. The *desmodium* variety was *Desmodium* silverleaf with a spacing of 35 cm inter-row and drilled in line. Land preparation consisted of the incorporation of FYM and inorganic fertilizer before planting. Two maize seeds were planted per hole and later thinned to one to attain the recommended 44,444 plants spacing per hectare.

### 2.3 Laboratory analyses of soil samples:

Soil samples were collected from each plot once every month for the whole growing season using a 5 cm wide soil auger to a depth of 0-20 cm and 20-40 cm. The samples were stored in plastic zip-lock bags and then transported to the laboratory, and analyzed within 24 hrs for nitrate ($NO_3^-$) and ammonium ($NH_4^+$). The colorimetric method was used to determine $NO_3^-$ and $NH_4^+$, measured at 419 and 655 nm wavelength, respectively (Okalebo et al., 2002). Soil bulk density was not monitored monthly but determined once at the beginning of the experiment, since it remains relatively stable over a cropping season (Okalebo et al., 2002)). Soil texture was determined by the hydrometer method as described by (Bouyoucos, 1962). Soil moisture content was determined gravimetrically by oven-drying 20 g of fresh soil at 105 °C for 24 hours, with results expressed as the percentage change in weight from fresh to dry soil. For chemical analyses, air-dried soils were sieved through a 2 mm mesh. Soil organic carbon (%C) was determined by the Walkley–Black wet oxidation method using potassium dichromate, sulfuric acid digestion followed by titration with ferrous ammonium sulfate (Okalebo et al., 2002). Soil pH was measured in a 1:2.5 (soil: water) suspension using a calibrated glass probe pH meter (LBI-449, India). Available P was determined using the Olsen method, where soil was extracted with 0.5 M $NaHCO_3$ solution (pH 8.5) and the absorbance of the extract was measured

at 880 nm using a spectrophotometer. Total N (%) was measured calorimetrically after Kjeldahl digestion, with absorbance read at 650 nm (Bremner & Mulvaney, 1982).

### 2.4 Initial Soil Characterization:

Initial soil characterization of the experimental site is presented in Tables 1. Soil pH were moderately acidic and ranges from 5.2 to 5.3. Total N was low at (0.10%), while that of available P was low (< 10 mg $kg^{-1}$). Organic carbon levels were moderate with values ranging 2.1- 2.78%. The soils were classified as clay loam.

**TABLE 1**

**INITIAL PHYSIOCHEMICAL PROPERTIES IN THE SOIL BEFORE EXPERIMENTAL SETUP; (KEIYO NORTH)**

| Soil Depth (cm) | Bulk Density (g $cm^{-3}$) | pH | Total Nitrogen (%) | Av. Phosphorus (mg $kg^{-1}$) | Organic C (%) | Texture |
|---|---|---|---|---|---|---|
| 0–20 | 1.22 | 5.3 | 0.11 | 9.06 | 2.64 | Clay loam |
| 20–40 | | 5.2 | 0.09 | 6.11 | 2.2 | |

***Values are means (n = 3)***

### 2.5 Plant Data Sampling and Analysis:

Maize and *Desmodium* Biomass Measurement Maize biomass was determined by sampling 16 plants within each 3 m x 3 m plot. Leaves were sampled at silking (15 weeks after planting), while grains and stovers were collected at harvest, air-dried for twenty-one days, and the dry weight was recorded. *Desmodium* biomass was measured by sampling eight rows of 3 m x 3 m within each plot. The data collected from maize and desmodium biomass measurements were used to compare the effects of different fertilizer treatments on crop performance and to identify the best fertilizer management practices that increase crop yield. Biomass measurements were essential in calculating the nutrient use efficiency (NUE). The total Biomass produced (both maize and *desmodium*) under different fertilizer inputs can indicate how efficiently the crops use the available nutrients. Equation 1 to 5 adopts the formula described by (Congreves et al., 2021).

### 2.6 Grain Yield Determination:

The number of plants in each effective sampling area was counted manually and recorded. Total and subsample fresh weights of the heads were measured per net effective area. The subsample was taken to the University of Eldoret for air drying in the greenhouse. The dry weights of the subsample were then measured. Grains were separated from stovers, and their dry weights were recorded. The grain yields were expressed in tons per hectare (t $ha^{-1}$).

$$Grain\ yield\ (t\ ha^{-1}) = \left(\frac{total\ sample\ fresh\ weight\ of\ cobs \times sub\ sample\ dry\ grain\ weight}{sub\ sample\ fresh\ weight}\right) \times 10{,}000\ m^2\ /9\ m^2 \quad (1)$$

### 2.6.1 Agronomic Use Efficiency:

It was determined by calculating the difference in grain yield with N application and without it, and then dividing the results by the amount of N applied, indicated by the following formula.

$$Agronomic\ N\ use\ efficiency) = \left(\frac{grain\ yield\ with\ N\ application - grain\ without\ N\ application}{amount\ of\ N\ applied}\right) \quad (2)$$

### 2.6.2 Grain N and P Uptake:

Dry grains were sampled in each treatment after harvesting period and ground into fine powder before analysis for P and N content as per the laboratory manual by Okalebo et al (2002). The amount of N and P uptake was calculated and expressed in kilograms per ha as indicated in the formulae.

$$Nitrogen\ uptake\ (kg\ ha^{-1}) = \left(\frac{N\ content\ \left(\frac{mg}{kg}\right)}{1000000}\right) \times yield\ (kg\ ha^{-1}) \quad (3)$$

$$Phosphorus\ uptake\ (kg\ ha^{-1}) = \left(\frac{P\ content\ \left(\frac{mg}{kg}\right)}{1000000}\right) \times yield\ (kg\ ha^{-1}) \quad (4)$$

### 2.6.3 Apparent Recovery:

It was determined by calculating the difference in total N uptake in above-ground biomass with and without N fertilization. The net amount of N absorbed was then divided by the amount of nutrient applied.

$$Apparent\ \ recovery\ efficiency(\%)\ = \left(\frac{Total\ N\ uptake\ of\ fertilized\ plants - Total\ N\ uptake\ of\ unfertilized\ plant}{Ferilizer\ N\ applied}\right) \quad (5)$$

## 2.7 Lab analysis: Nitrogen and Phosphorus Analyses for Plants

From each powdered sample of leaves, stovers, and grains, 0.3 g was mixed with 4.4 ml of digestion mixture (composed of hydrogen peroxide, sulfuric acid, selenium, and salicylic acid) and stored at 2°C in digestion tubes. The mixture was digested in a block digester at 360°C for 2 hours. After digestion, the mixture was cooled and transferred to 50 ml volumetric flasks. The solution was made up to volume with distilled water, and 5 ml aliquots were taken for analysis. Percentage N and P were determined separately using the colorimetric method described by (Okalebo et al. 2002). Using a spectrophotometer, N absorbance was measured at 650 nm, while P absorbance was determined at an 880 nm wavelength.

## 2.8 Statistical analysis:

Data were analyzed using R (version 4.4). For soil parameters ($NO_3^-$-N, $NH_4^+$-N, Total N, C, P, and pH), a linear mixed-effects model was fitted with treatment and cropping system as fixed effects and replicate as a random effect. For plant nutrient data (%N and %P), a two-way ANOVA was used to assess differences among treatments and cropping systems. Post hoc comparisons were conducted using Tukey's HSD test at $p \leq 0.05$. Agronomic efficiency (AE) and recovery efficiency (RE) were analyzed through one-way ANOVA since only treatment effects were considered. Pearson correlation and principal component analyses (PCA) were performed to explore relationships among soil, plant, and efficiency variables. All data were visualized using ggplot2, showing mean ± standard error bars and multivariate relationships.

# III. RESULTS

## 3.1 Soil Nutrients Dynamics:

### 3.1.1 $NO_3$-N Concentration:

(Figure 2), shows that $NO_3^-$-N concentrations peaked between DAP 30 and DAP 180 in the 0–20 cm soil layer and steadily declined toward harvest (DAP 210).

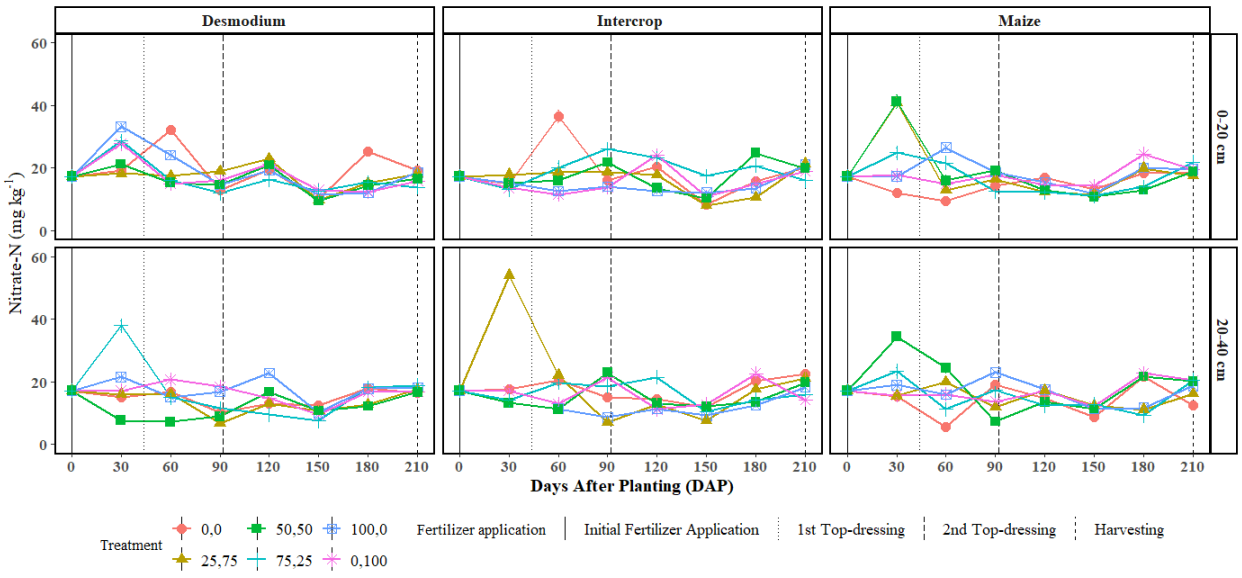



**FIGURE 2: Soil Nitrate (mg $kg^{-1}$ soil), for Desmodium, Intercrop & Maize Cropping System at 0- 20, 20-40 cm depth.**

### 3.1.2 $NH_4^+$-N Concentration:

Ammonium-N levels fluctuated over time as shown in figure 3, with peaks observed after DAP 30 and 90, especially in the 0–20 cm soil layer.

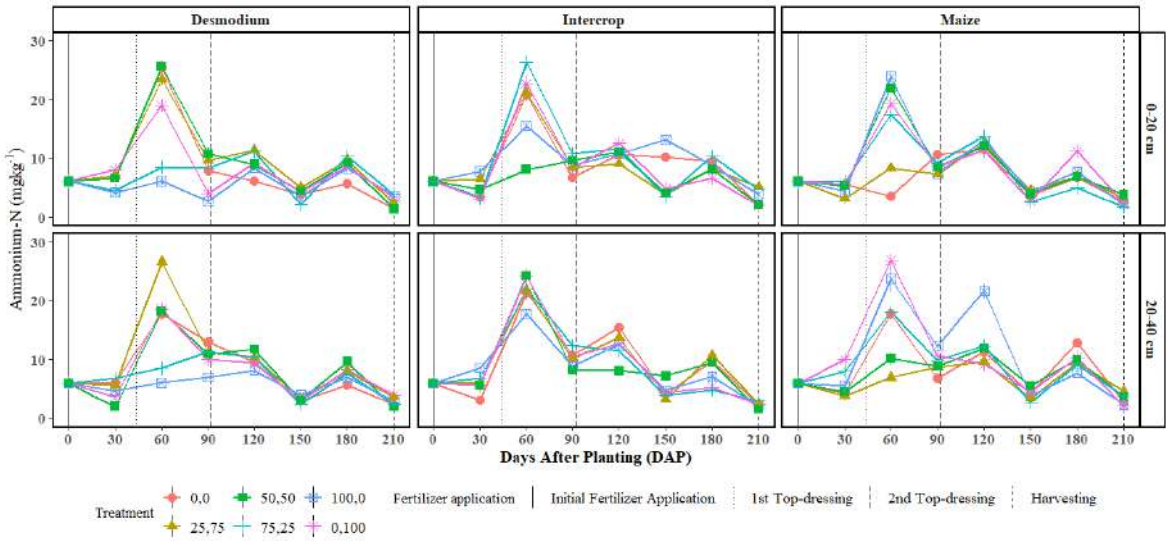



**FIGURE 3: Soil Ammonium (mg kg$^{-1}$ soil), for Desmodium, Intercrop & Maize Cropping System at 0- 20, 20-40 cm depth.**

These peaks aligned with periods immediately after the first topdressing, which involved urea fertilizer. The surface soils showed a range of 3.5–7.5 mg/kg, while in the 20 - 40 cm depth, values were generally lower (2.0–5.0 mg/kg). After DAP 120, a gradual decrease in $NH_4^+$ concentrations were observed across all cropping system. Treatment 100,0 (FYM-only) and 75,25 (75% FYM + 25% inorganic) combinations consistently recorded the highest $NH_4^+$ concentrations, with peaks reaching 22.5 mg/kg at DAP 60–90 in surface soils. Fertilizer treatments 0,100 (100% inorganic) and 0,0 (no fertilizer) had the lowest $NH_4^+$ levels throughout the season, rarely exceeding 15 mg/kg even at peak times The 25,75 and 50,50 fertilizer rates demonstrated intermediate values**.** *Desmodium* systems maintained higher $NH_4^+$ concentrations for a longer period into the season, especially under 25,75, 75,25, and 100,0 fertilizer rates. The $NH_4^+$ concentrations peaked at 25 mg/kg around DAP 60 and remained above 5 mg/kg even at DAP 150 in some plots. The maize-*desmodium* intercrop showed intermediate $NH_4^+$ levels, peaking at 6.0–27 mg/kg at DAP 60 under the 50,50 and 75,25 treatments. Maize plots showed early peaks in $NH_4^+$ (DAP 30–60), followed by a sharp decline by DAP 150, especially in the 0 100, 100 0, 25 75, and 75 25 fertilizer combinations. Peak $NH_4^+$ levels for maize ranged from 15 to 25 mg/kg in the surface layer.

### 3.1.3 Soil pH:

Fertilizer treatment significantly affected soil pH ($p < 0.001$), with FYM-based treatments maintaining higher pH levels (6.3–6.5), while plots receiving 100% inorganic N (urea) showed lower pH (5.2).

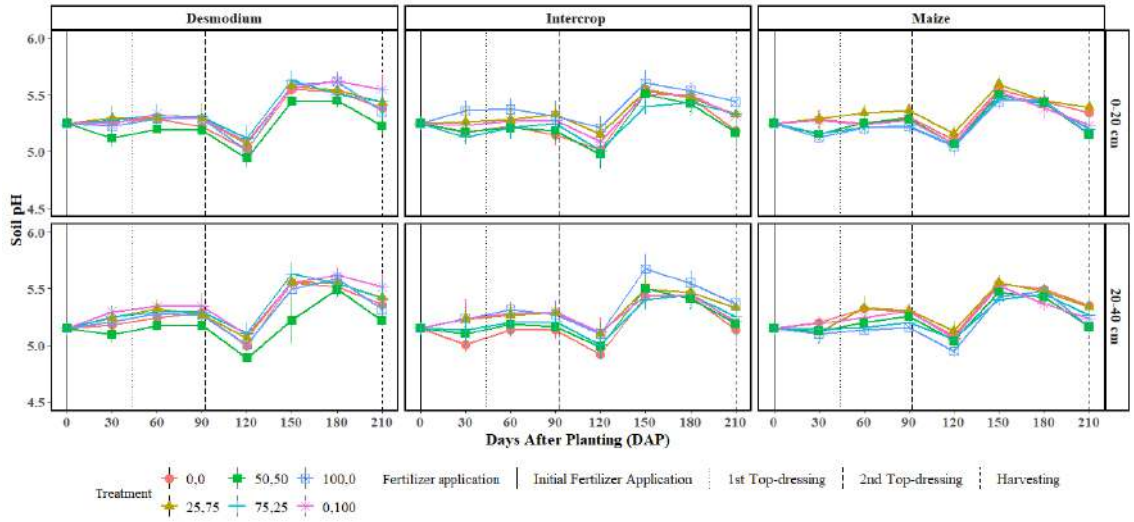



**FIGURE 4: Soil pH, for Desmodium, Intercrop & Maize Cropping System at 0- 20, 20-40 cm depth**

Soil pH values across all cropping systems ranged from 5.0 to 6.5, placing the soils in the slightly acidic to near-neutral range. The pH values were consistently higher in the surface layer (0–20 cm) than in the subsoil (20–40 cm) as shown in figure 3. Throughout the cropping season, a trend of pH increase was observed around DAP 90 and DAP 180, coinciding with topdressing fertilizer applications. Among the fertilizer treatments, plots amended with higher FYM to inorganic combinations (75,25 and 100,0) consistently maintained higher soil pH, especially in desmodium and intercrop systems.

### 3.1.4 Available Phosphorus:

Fertilizer treatments had a statistically significant effect on available phosphorus at 0–20 cm in $p < 0.05$), where FYM-rich plots (75,25 and 50,50) exhibited higher P levels (mean > 10 mg/kg). At deeper depths (20-40cm) the differences were not significant ($p > 0.05$), indicating that P dynamics are localized at the surface as shown in figure 5a. Across the three cropping systems, available phosphorus (P) concentrations displayed clear temporal trends. Values increased significantly from DAP 0 to DAP 90–150, then slightly decreased by harvest (DAP 210). The most notable increases occurred in the 0–20 cm depth. Available P ranged from as low as 4 mg/kg in 0,0 (control) to over 20 mg/kg in 50,50 and 75,25 fertilizer regimes, at peak times (DAP 150). As shown in Figure (5a)

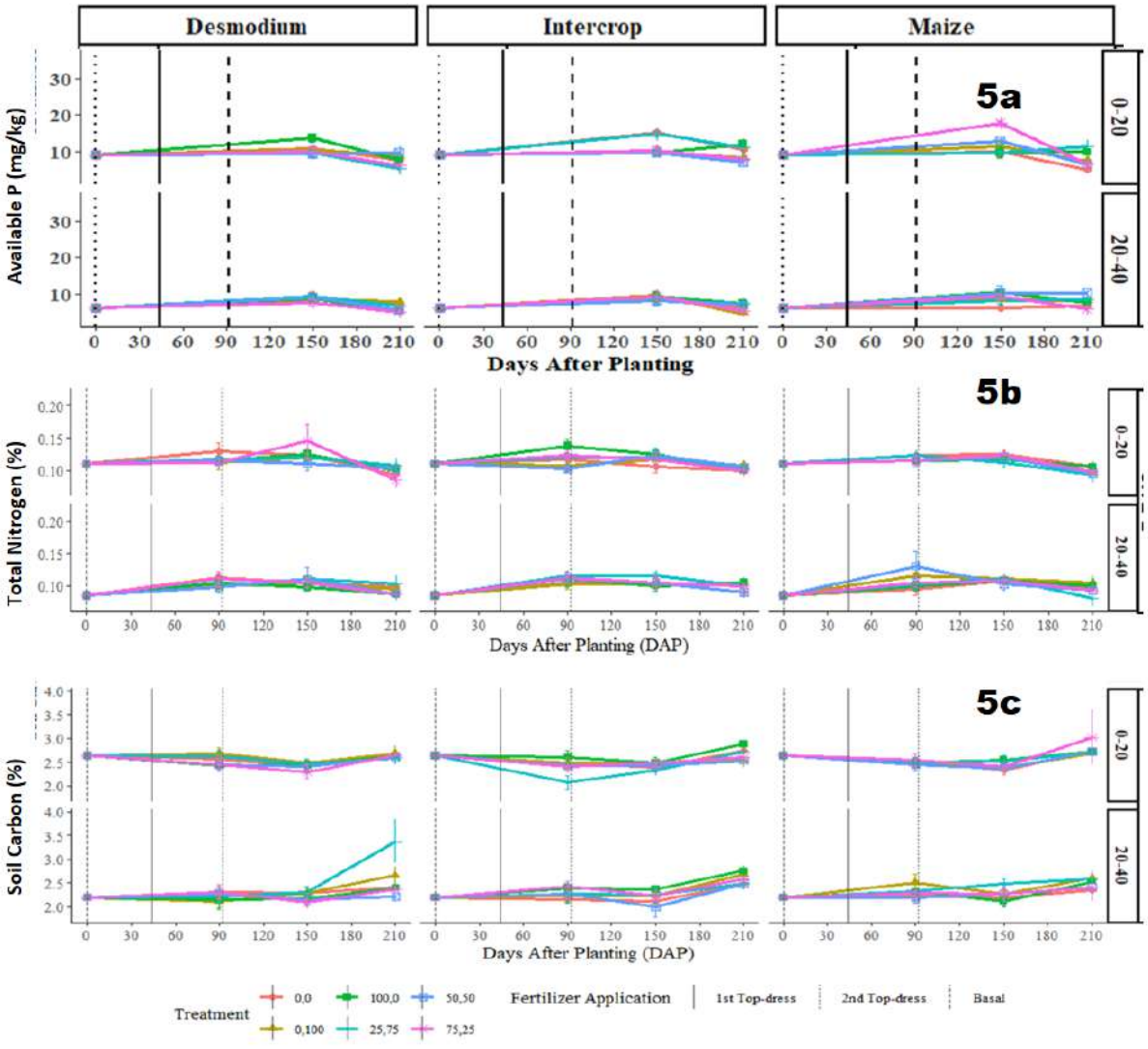



**FIGURE 5a: Soil Available Phosphorus (mg/kg), (5b) Soil Nitrogen (%), (5c) Soil Carbon (%), for Desmodium, Intercrop & Maize Cropping System at 0- 20, 20-40 cm depth.**

*Desmodium* plots consistently maintained higher available P, especially at the 0–20 cm depth. Peak values in 75,25 and 50,50 reached up to 24 mg/kg at DAP 150, declining slightly to 18 mg/kg at harvest. The intercrop exhibited intermediate but stable P concentrations, typically ranging from 14 to 20 mg/kg under FYM-inclusive treatments. Sole maize systems showed greater variability and faster P decline, particularly by DAP 180 to 210, even under 50,50 and 75,25. Although values reached 20

mg/kg at DAP 150, they dropped to 12–14 mg/kg at harvest. Deeper layers (20–40 cm) under maize often remained below 10 mg/kg.

### 3.1.5 Soil Total Nitrogen:

There were no statistically significant differences in total soil nitrogen across treatments and depth (ANOVA $p > 0.05$). Total nitrogen (%) exhibited a clear temporal pattern across all cropping systems and treatments as shown in figure 6**.** The initial values at DAP 0 were relatively consistent and low, Nitrogen concentrations rose by DAP 90 and a peak in total N was consistently observed around DAP 150, Subsequently, N levels declined toward DAP 210 (harvest). The 0–20 cm depth consistently showed higher nitrogen percentages than the 20–40 cm layer across all treatments and cropping systems. The 50,50 (50% FYM + 50% inorganic) and 75,25 fertilizer combinations maintained the highest total N concentrations throughout the season. In contrast, 0,0 (no fertilizer) and 0,100 (sole inorganic) plots consistently had lower total nitrogen values across the season. Meanwhile, 0,100 exhibited sharp declines post-DAP 90, especially in maize systems. *Desmodium* plots consistently recorded higher nitrogen concentrations, especially in the surface layer (0–20 cm) as shown in (5b) Even the 0,0 desmodium plots maintained relatively stable N levels compared to maize.

### 3.1.6 Soil Total Organic Carbon:

In figure (5c), Soil organic carbon was minimally impacted by fertilizer treatments at both depths ($p = 0.069$). The highest carbon levels were seen under 75,25 and 100,0 fertilizer combinations (means = 2.93% and 2.91%, respectively). Across all cropping systems and treatments, SOC was consistently higher at 0–20 cm than at 20–40 cm. Fertilizer treatments had a pronounced influence on soil carbon levels. Plots receiving high FYM inputs, 75,25 (75% FYM) and 100,0 (100% FYM)**,** recorded the highest SOC concentrations**,** reaching up to 2.1% in topsoil by DAP 150, particularly under *Desmodium* and intercrop systems. Plots under 0,0 (no fertilizer) and 0,100 (100% inorganic fertilizer) had the lowest SOC values across all depths, generally remaining below 1.0%**.** The 25,75 and 50,50 fertilizer rates, which combined FYM with mineral fertilizers, showed intermediate SOC levels (1.2–1.7%). The *Desmodium* cropping system consistently exhibited the highest SOC values, especially at the 0–20 cm depth and during the mid-season (DAP 90–150). Peak SOC levels in *desmodium* plots with 75,25 and 100,0 reached approximately 2.1%, which was significantly higher than maize or intercrop. The intercrop system showed moderate SOC values, generally ranging from 1.2–1.8% in surface soils. The FYM-rich combinations under intercropping (50,50 and 75,25) maintained stable SOC levels throughout the season. Sole maize plots had the lowest SOC content, especially under 0,0 and 0,100 fertilizer rates. Maximum values were rarely exceeded at DAP 150, and subsoil values dropped to approximately 0.4–0.6%. In FYM-treated plots (50,50 and 75,25), SOC levels improved, reaching around 1.7%, but remained lower than *desmodium*.

## 3.2 Crop Performance and Plant Nutrition:

### 3.2.1 Maize grain Yield:

Grain yield maize monocrop varied significantly across treatments ($p < 0.05$), ranging from approximately 4.5 t/ha in the 0,0 treatment to a peak of about 6.8 t/ha under the 0,100 treatment as shown in figure 6.

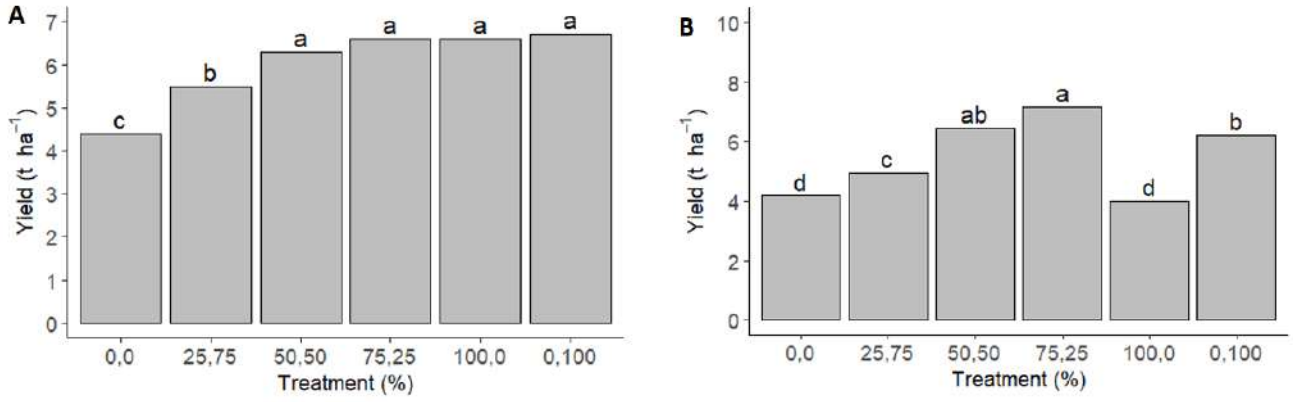



**FIGURE 6: A & B are Maize Monocrop and Maize Intercrop Yield Respectively.**

Grain yields were generally lower (4.5–6.5 t/ha), possibly due to reduced soil fertility. The highest yields were observed under 50,50, 75,25, and 100,0 fertilizer rates, all of which were statistically similar (6.0–6.5 t/ha). The lowest yield (4.5 t/ha) in the 0,0 treatment. In comparison, the moderate yield under 0,100 (6.0 t/ha). In the intercrop system, yields ranged from approximately 4.5 t/ha (0,0 and 100,0) to around 8.0 t/ha under 50,50 and 75,25, which were statistically the highest

### 3.2.2 Nitrogen Uptake (kg N ha-[1]):

In maize monocrop, nitrogen uptake ranged from about 60 kg N/ha (0,0) to approximately 90 kg N/ha (50,50, 75,25, 100,0, and 0,100), all of which were statistically similar *(Figure 7 a)*. N uptake was consistently higher across all rates, ranging from approximately 60 kg N/ha (0,0) to around 95 kg N/ha (50,50, 75,25, 0,100). Statistically, all treatments except the control (0,0) and 25,75 performed similarly *(Figure7 b)*.

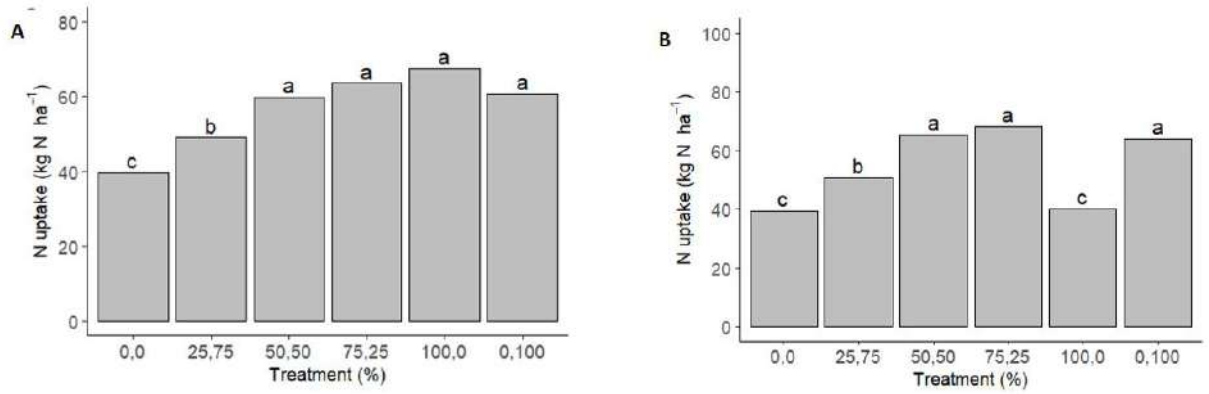



**FIGURE 7: A & B are Maize Monocrop and Maize Intercrop N Uptake (kg N ha$^{-1}$) Respectively.**

### 3.2.3 Phosphorus Uptake (kg P ha[1]):

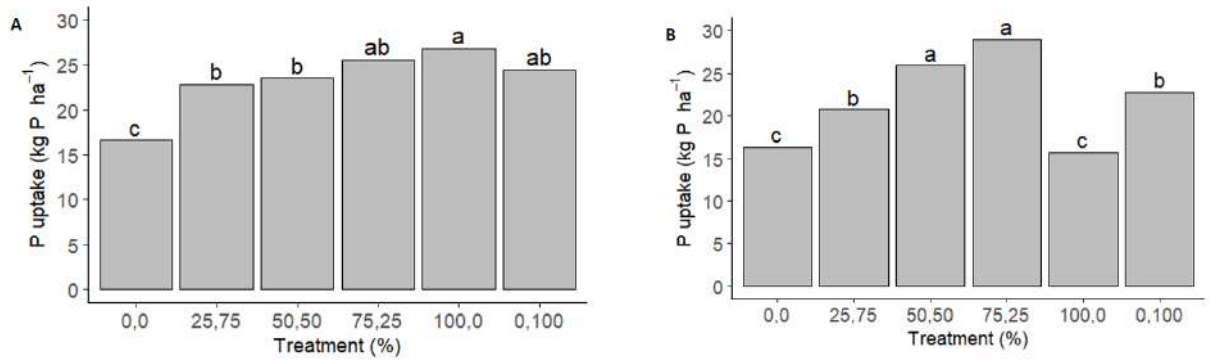



**FIGURE 8: A & B are Maize Monocrop and Maize Intercrop P Uptake (kg P ha$^{-1}$) Respectively.**

P uptake ranged from about 16 kg/ha (0,0) to 27 kg/ha (75,25) *(Figure 8 a)*, with all treatments, including FYM (50,50, 75,25, 100,0), performing well. Intercrop, P uptake was highest under the 75,25 and 50,50 fertilizer rates (28–30 kg/ha), significantly greater than under the 0,0 and 100,0 treatments (17 kg/ha) *(Figure 8 b)*.

### 3.3 Desmodium Biomass Yield:

*Desmodium* yield varied significantly **(**$p < 0.0001$**)** across treatments and cropping systems. Under sole *desmodium* cropping**,** yield ranged from 1.86 t/ha (0,0) to a maximum of 6.29 t/ha (75,25)**.** The highest yield under intercrop was observed with 75,25 (FYM) at 2.42 t/ha**,** followed by 0,100 (2 t/ha) and 100,0 (1.84 t/ha) as shown in figure 9 D Notably, intercropped *Desmodium* in the control (0,0) recorded the lowest yield (0.77 t/ha), indicating the necessity of nutrient input.

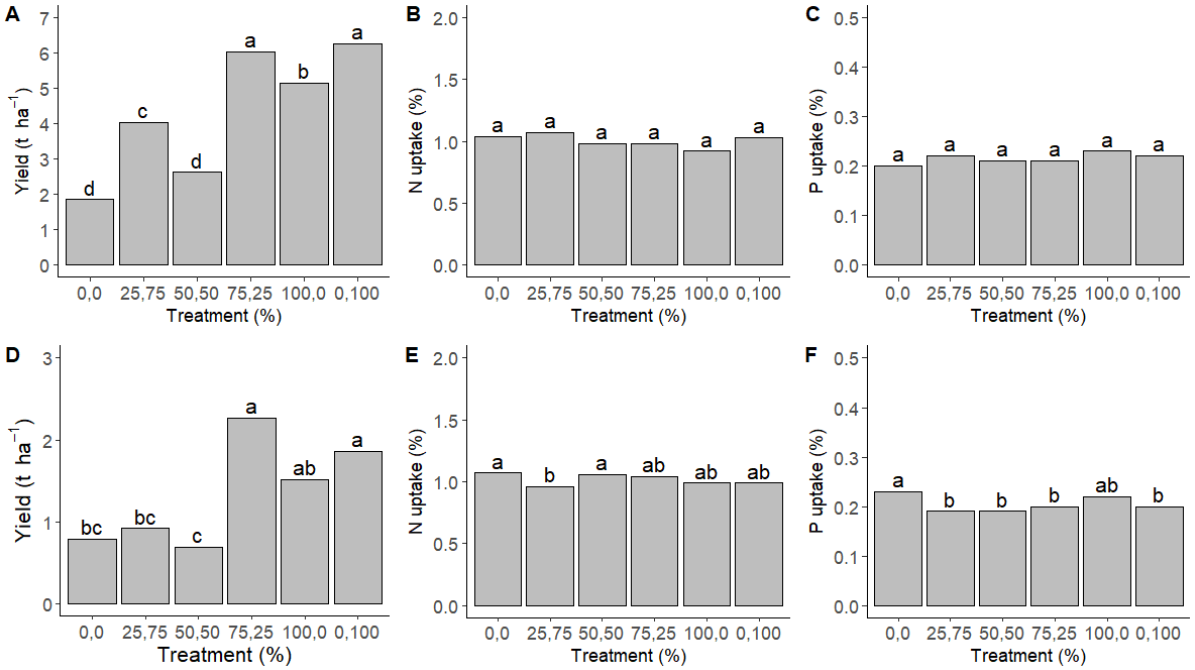



**FIGURE 9: A-Yield (t/ ha$^{-1}$), B- N Uptake (kg N ha$^{-1}$), C- P Uptake (kg P ha$^{-1}$) for Desmodium Monocrop and D- Yield (t/ ha$^{-1}$), E- N Uptake (kg N ha$^{-1}$), F- P Uptake (kg P ha$^{-1}$) for Desmodium Intercrop.**

### 3.3.1 Nitrogen Uptake (% N):

*(Figure 9 b)*, shows a statistically significant effect observed ($p < 0.0001$)**,** with generally higher N content in intercrops **(**mean = 1.01%**)** compared to sole crops **(**0.89%). The highest N uptake was observed under intercrop with 50,50 and 75,25, both at 1.06–1.04%**,** whereas the lowest was under sole cropping at 0,100 (0.97%)**.**

### 3.3.2 Phosphorus Uptake (% P):

*(Figure 9 c & f)*, shows both sole and intercropped *Desmodium* showed high P uptake across the fertilizer regimes, ranging between 0.20–0.23%**.** Notably, 0,0 still exhibited the highest %P in monocrop (0.99%) and intercrop (0.23%).

### 3.4 Nutrient Use Efficiency:

### 3.4.1 Agronomic efficiency AE:

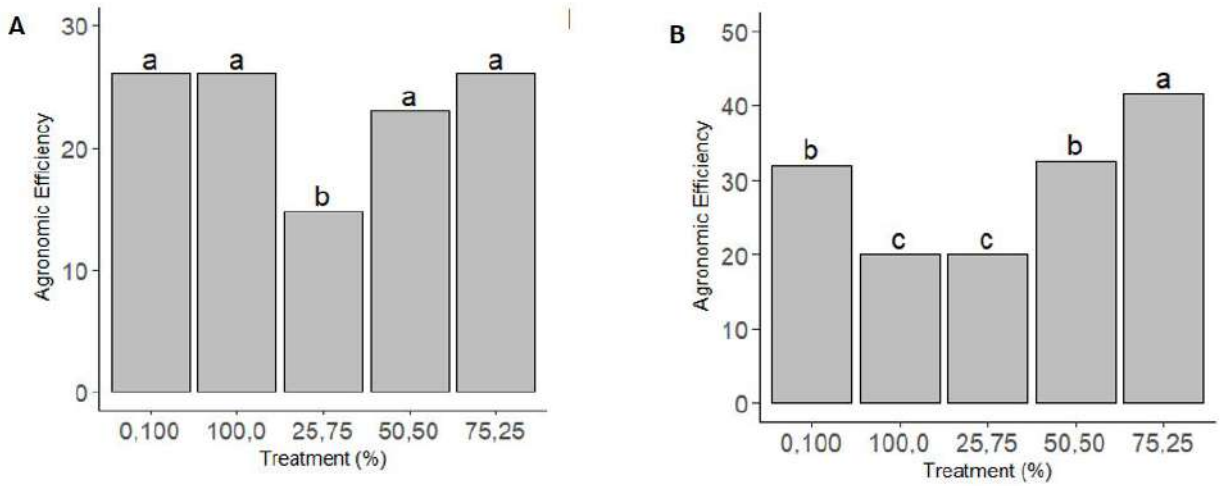



**FIGURE 10: A & B is Maize Monocrop and Maize Intercrop Agronomic Efficiency Respectively.**

For maize monocrop, *(Figure 10 a)***,** AE was highest in the 25,75 and 75,25 combinations (around 35 kg/kg), followed by the 50,50 ratios (about 30 kg/kg). The 100,0 ratio had the lowest AE (around 15). For maize in intercrop ***(****Figure 10 b)***,** the 75,25

fertilizer combinations showed the highest AE (40 kg/kg), while the 25,75 and 50,50 ratios ranged from 25 to 30. FYM-only and 0,100 had poor agronomic efficiency**.**

### 3.4.2 Recovery Efficiency (RE):

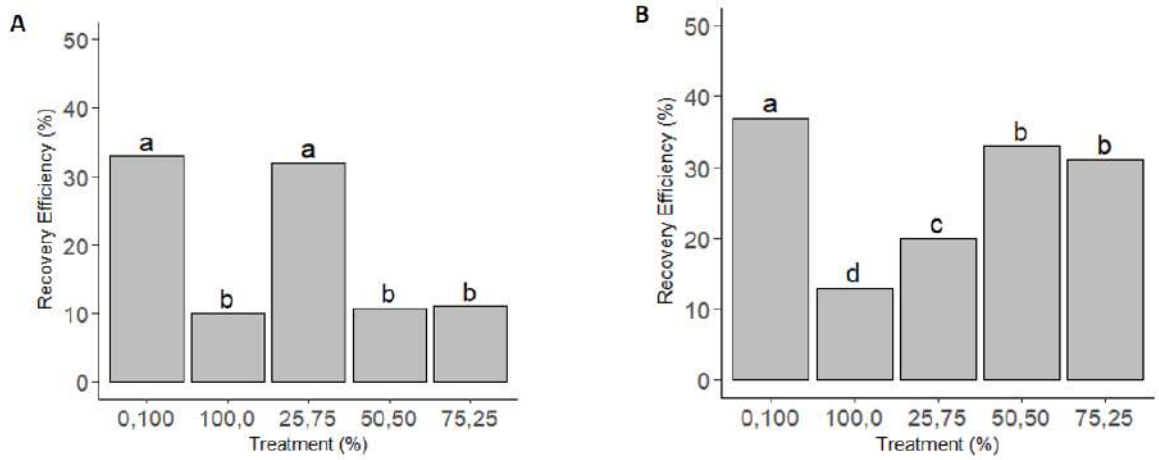



**FIGURE 11: A & B is Maize Monocrop and Maize Intercrop Recovery Efficiency Respectively.**

Maize monocrop ***(****Figure 11 a)****,*** 0,100 and 25,75 fertilizer combinations had the highest RE (35%), making them statistically significant. Maize intercrop in ***(****Figure 11 b****),*** RE peaked at 0,100 (40%)**,** followed by 50,50 and 75,25 (35%)**.** 100,0 had the lowest RE (15%)**,** while 25,75 was also lower (25%).

## IV. DISCUSSION

### 4.1 Soil Nutrients Dynamics:

Nitrate dynamics varied strongly with fertilizer type. Early-season $NO_3^-$ peaks occurred in inorganic-dominated treatments (25,75 and 0,100) due to rapid urea hydrolysis and nitrification after fertilizer application. These peaks were short-lived, likely due to plant uptake and leaching losses. In contrast, FYM-rich treatments (75,25 and 100,0) maintained moderate, stable $NO_3^-$ levels, reflecting slower N release through mineralization and better synchrony with crop demand. The 50,50 combination balanced rapid mineral N supply with sustained release from FYM, while the control (0,0) had the lowest $NO_3^-$ due to nutrient limitation. These findings agree with (Sahoo et al., 2022), who reported that urea drives early nitrate surges while organic sources buffer N release over time. Cropping systems also influenced nitrate availability. *Desmodium* plots showed consistently lower $NO_3^-$ levels, suggesting efficient uptake through symbiotic N fixation, while intercrops exhibited intermediate levels due to complementary N use between maize and desmodium. This supports (Giller & Cadisch, 1995), who noted that cereal-legume intercrops enhance nutrient-use efficiency and reduce nitrate losses.

Ammonium ($NH_4^+$) levels were significantly affected by cropping system and fertilizer type. FYM-based treatments (100,0 and 75,25) recorded the highest $NH_4^+$ due to continuous organic N mineralization, while 0,100 and 0,0 had the lowest levels. Balanced treatments (25,75 and 50,50) showed intermediate values, indicating steady N supply from both sources, consistent with (Aboyeji et al., 2019). *Desmodium* and intercrop systems maintained higher $NH_4^+$ for longer, likely due to reduced nitrification from legume-released inhibitors (Subbarao et al., 2007) and biological N fixation that conserved soil $NH_4^+$.

Soil pH responded distinctly to fertilizer type and cropping system. FYM-based treatments maintained higher pH values (6.3-6.5), while plots receiving 100% inorganic N (urea) showed lower pH (around 5.2), consistent with urea-induced acidification during nitrification (M. Zhou et al., 2017). The addition of FYM increased soil pH by supplying base cations ($Ca^{2+}$, $Mg^{2+}$, $K^+$, $Na^+$), improving cation exchange capacity (CEC), and promoting microbial $CO_2$ release that enhances carbonate buffering. Conversely, urea and TSP application increased $H^+$ concentration through nitrification and phosphate fixation, contributing to soil acidification. A significant interaction between fertilizer regime and cropping system indicated that *desmodium*-based systems buffered soil acidity more effectively than sole maize, likely due to rhizobial activity and higher organic inputs. Across all treatments, pH tended to be slightly lower in deeper layers, reflecting leaching of acidic ions and reduced organic matter influence in subsoil horizons. These results align with (Girma et al., 2020), who reported that organic amendments enhance pH

buffering in acid-prone tropical soils. Throughout the cropping season, a gradual rise in pH coincided with topdressing events, particularly in FYM-amended plots, indicating the alkaline buffering effect of organic inputs. *Desmodium* plots consistently recorded the highest surface pH values, attributed to root exudates and microbial activity that stabilize rhizosphere pH. In contrast, maize plots under high inorganic fertilizer rates (0,100 and 25,75) had the lowest pH, showing stronger acidification effects. The intercrop maintained intermediate values, reflecting nutrient complementarity between maize and *desmodium*.

Fertilizer treatments significantly influenced available phosphorus, indicating enhanced solubilization from FYM through microbial phosphate mobilization (Richardson & Simpson, 2011). Phosphorus levels increased notably in the 020 cm layer, reflecting surface enrichment from fertilizer and organic matter decomposition. The 50,50 and 75,25 treatments consistently recorded the highest available P, attributed to organic acids released during FYM decomposition that dissolve bound phosphates and stimulate microbial mineralization. In contrast, the 0,100 (sole inorganic) plots had the lowest P levels due to phosphate fixation in acidic conditions and the absence of organic chelating agents, while the 0,0 control remained nutrient-depleted. *Desmodium* plots maintained higher available P, likely due to rhizosphere acidification and organic acid exudation (Bhuyan et al., 2020), which mobilized P and enhanced microbial biomass. Intercropping sustained moderate but stable P levels, benefiting from nutrient complementarity between maize and desmodium (Jin et al., 2024). Sole maize plots showed faster P decline, reflecting high uptake and limited recycling. Overall, balanced organic-inorganic fertilization (50,50) optimized P availability and uptake efficiency in these highland soils.

Total nitrogen peaked around DAP 150, reflecting active N cycling, root exudation, and microbial activity before declining toward harvest due to crop uptake and potential losses. The 50,50 and 75,25 treatments maintained the highest total N concentrations, attributed to synchronized release where FYM supplied slow-release organic N and inorganic fertilizer provided readily available forms (Palm et al., 2001). In contrast, 0,0 and 0,100 plots recorded the lowest N, the latter declining sharply after DAP 90 due to leaching and rapid plant uptake. *Desmodium* plots consistently exhibited the highest N levels owing to biological nitrogen fixation and enhanced microbial biomass supported by FYM (Freyer & Bingen, 2021). The intercrop maintained stable intermediate N concentrations, benefiting from complementary N acquisition where *desmodium* fixed atmospheric N and maize utilized mineral N (Giller & Cadisch, 1995). Sole maize plots, especially under 0,100, showed sharp declines post-silking due to intensive uptake and low buffering capacity. Overall, integrating FYM with inorganic N (particularly 50,50) sustained higher N availability and improved soil fertility through enhanced microbial cycling and reduced losses.

Soil organic carbon (SOC) showed temporal and spatial variation, with higher values in surface soils (0–20 cm). FYM application significantly increased SOC through additions of both labile fractions that fuel microbial activity and recalcitrant carbon that enhances long-term sequestration and soil structure (Palm et al., 2001). The 50,50 and 75,25 treatments maintained higher SOC, while 0,0 and 0,100 plots had the lowest due to lack of organic input and faster mineralization. *Desmodium* plots recorded the highest SOC, attributed to dense root biomass, nitrogen fixation, and rhizo-deposition that enrich soil organic matter (Drinkwater et al., 1998). The intercrop maintained moderate but stable SOC levels, benefiting from root complementarity and slower decomposition rates under FYM-inclusive regimes (F. Zhang & Li, 2003). Sole maize plots had the lowest carbon due to lower residue return and rapid decomposition. Overall, FYM-based combinations (especially 50,50) improved SOC accumulation, supporting balanced C:N ratios, better mineralization, and long-term fertility in the Keiyo North Nitisols.

### 4.2 Maize Yield, Biomass, and Nutrient Uptake (N and P):

Maize yield and nutrient uptake in Keiyo North responded strongly to fertilizer type and combination, with FYM-rich treatments performing best overall. The highest yields were recorded under the 50,50, 75,25, and 100,0 fertilizer rates, all statistically comparable, indicating that organic inputs enhanced productivity by improving soil moisture retention and nutrient synchrony. The lowest yield in the 0,0 treatment confirmed nutrient limitations, while the moderate yield under 0,100 reflected the immediate but short-lived nutrient supply from urea without the buffering benefits of FYM. These findings agree with (Kamau et al., 2022), who reported that organic inputs enhance soil resilience and crop yield stability under moisture-limited conditions. In intercrop systems, FYM–inorganic blends produced the highest yields, highlighting improved rhizospheric interactions and biological nitrogen fixation (BNF) by desmodium, consistent with (Wanyama et al., 2023), who showed that FYM integration enhances intercrop productivity and land-use efficiency under variable rainfall.

Biomass accumulation followed a similar pattern, with the 50,50 and 75,25 combinations producing the highest values. The strong performance of FYM-inclusive treatments reflects enhanced soil structure, microbial activity, and nutrient availability that support both vegetative and reproductive growth. Lower biomass under 0,0 and 0,100 treatments underscores the limited

water retention and nutrient buffering in the absence of organic matter. The results align with (Mucheru-Muna et al., 2021), who emphasized the synergy between FYM and inorganic N for optimal maize biomass accumulation.

Nitrogen uptake was highest in the 50,50 treatment, confirming the synergistic effect of combining fast-release urea with slow-mineralizing FYM to ensure continuous N supply throughout the season. FYM improved nitrogen use efficiency by enhancing microbial activity and soil aeration, minimizing leaching and volatilization losses. The 100,0 treatment lagged behind, likely due to slow mineralization that failed to meet maize's early N demand. Intercropping further improved N uptake through BNF by desmodium and complementary root systems that enhanced N retention and minimized loss pathways, consistent with (J. M. Kihara & Bolo et al., 2021). The pattern supports the findings of (Breure et al., 2023) that partial substitution of urea with FYM increases N uptake efficiency and resilience under fluctuating moisture conditions.

Phosphorus uptake followed similar trends, with the 75,25 and 50,50 treatments showed the highest value in intercrops. The improved uptake reflects FYM's ability to mobilize occluded P through organic acid release and stimulation of microbial P cycling (Jairus et al., 2021). The synergistic effects of *desmodium's* rhizosphere acidification and FYM-induced mineral dissolution enhanced P availability and plant uptake. In contrast, 0,0 and 0,100 treatments recorded the lowest uptake, reflecting P deficiency and fixation in acidic soils. These results confirm (Arruda et al., 2019), who found that combining organic and inorganic sources optimizes P solubility and root acquisition efficiency.

### 4.3 Desmodium Yield, and Nutrient Uptake (N and P):

*Desmodium* yield trends indicate that organic nutrient sources more effectively support its growth. Similar findings by (Kassaw & Alemu et al., 2022) reported improved *Desmodium* yields under balanced nutrient application and favorable microclimatic conditions. However, (J. M. Kihara & Bolo et al., 2021) observed reduced biomass under full FYM due to delayed nutrient release in cooler environments, suggesting site-specific responses.

Nitrogen uptake was generally higher in intercropped *Desmodium* than in sole stands, with the greatest values recorded under the 50,50 and 75,25 treatments. This enhancement is likely associated with improved root nodulation and biological nitrogen fixation (BNF) in intercrops under favorable soil conditions (Ndung'u et al., 2021).

Both sole and intercropped Desmodium exhibited high P uptake across fertilizer regimes. Interestingly, even the control (0,0) showed the highest %P concentration in both systems, suggesting that *Desmodium* efficiently acquires P from low-input soils, possibly through root exudates or mycorrhizal associations (Macharia et al., 2020). However, yield-based P uptake was greater under 0,100 and 25,75 treatments, corresponding with higher biomass production in these plots.

### 4.4 Agronomic and Recovery Efficiency:

In the maize monocrop, AE was highest under the 25,75 and 75,25 fertilizer combinations, followed closely by the 50,50 ratio. The 100,0 treatment recorded the lowest AE, highlighting limited N availability from organic sources alone. All AE values fell within or above the critical benchmark of 15–30 kg $kg^{-1}$ recommended for smallholder systems(W. Zhang et al., 2016). The strong performance of 25,75 and 75,25 confirms that combining fast-acting inorganic N with a slower-release organic source enhances nutrient synchronization and minimizes leaching losses, consistent with (C. Zhou et al., 2021). In intercrops, AE was highest under 75,25, whereas FYM-only and 0,100 treatments performed poorly, reflecting nutrient imbalances or legume–maize N competition in low-N regimes. The intercrop advantage likely arises from greater root diversity and improved soil nutrient exploration, though high FYM proportions may limit maize N uptake due to *Desmodium's* early N demand and possible suppression of nitrification (J. M. Kihara & Bolo, 2021).

In the maize monocrop, RE was greatest under the 0,100 and 25,75 fertilizer combinations, significantly outperforming other treatments, while 100,0 and 75,25 recorded the lowest values. The higher RE under mineral N treatments suggests rapid N availability, particularly in drier or cooler conditions, supporting (Bhardwaj et al., 2021), who observed low RE under sole FYM due to delayed mineralization. In the intercrop, RE peaked under 0,100, followed by 50,50 and 75,25, whereas 25,75 and 100,0 showed reduced efficiency. The relatively high RE under 0,100 and 50,50 implies that biological nitrogen fixation (BNF) from *Desmodium* likely supplemented soil N, reducing maize dependence on applied fertilizer and improving overall nutrient use efficiency.

## V. CONCLUSION

From this study, it is concluded that: (i) Fertilizer substitutions are important: Combining inorganic N with FYM, especially at 50,50 or 25,75, improved nutrient uptake, maize and *desmodium* biomass yields. (ii) The cropping system influences outcomes:

Intercropping maize with *desmodium* increased N uptake compared to sole maize, due to better root interactions and nitrogen fixation. Based on the above findings, the following recommendations are made: (i)Implement integrated nutrient management strategies, particularly 50,50, 75,25 and FYM-inorganic combinations, for maize and *desmodium* cropping systems they reliably enhance yields, nutrient use efficiencies, and lower emission intensities. (ii) Promote maize-desmodium intercropping in ASALs and other smallholder systems, especially where nitrogen fixation and erosion control are important. This intercropping method has shown agronomic and environmental advantages over monocropping.

## REFERENCES


[1] Abate, T., Fisher, M., Abdoulaye, T., Kassie, G. T., Lunduka, R., Marenya, P., & Asnake, W. (2017). Characteristics of maize cultivars in Africa: How modern are they and how many do smallholder farmers grow? *Agriculture & Food Security*, *6*(1), 30. https://doi.org/10.1186/s40066-017-0108-6

[2] Aboyeji, C. M., Adekiya, A. O., Dunsin, O., Agbaje, G. O., Olugbemi, O., Okoh, H. O., & Olofintoye, T. A. J. (2019). Growth, yield and vitamin C content of radish (Raphanus sativus L.) as affected by green biomass of Parkia biglobosa and Tithonia diversifolia. *Agroforestry Systems*, *93*(3), 803–812. https://doi.org/10.1007/s10457-017-0174-6

[3] Arruda, B., Rodrigues, M., Gumiere, T., Richardson, A. E., Andreote, F. D., Soltangheisi, A., Gatiboni, L. C., & Pavinato, P. S. (2019). The impact of sugarcane filter cake on the availability of P in the rhizosphere and associated microbial community structure. *Soil Use and Management*, *35*(2), 334–345. https://doi.org/10.1111/sum.12484

[4] Bhardwaj, A. K., Rajwar, D., Yadav, R. K., Chaudhari, S. K., & Sharma, D. K. (2021). Nitrogen Availability and Use Efficiency in Wheat Crop as Influenced by the Organic-Input Quality Under Major Integrated Nutrient Management Systems. *Frontiers in Plant Science, Volume 12-2021*. https://www.frontiersin.org/journals/plant-science/articles/10.3389/fpls.2021.634448

[5] Bhuyan, B., Debnath, S., & Pandey, P. (2020). The Rhizosphere Microbiome and Its Role in Plant Growth in Stressed Conditions. In S. K. Sharma, U. B. Singh, P. K. Sahu, H. V. Singh, & P. K. Sharma (Eds.), *Rhizosphere Microbes: Soil and Plant Functions* (pp. 503–529). Springer. https://doi.org/10.1007/978-981-15-9154-9_21

[6] Bouyoucos, G. J. (1962). Hydrometer Method Improved for Making Particle Size Analyses of Soils. *Agronomy Journal*, *54*(5), 464–465. https://doi.org/10.2134/agronj1962.00021962005400050028x

[7] Breure, M. S., Njoroge, S., Pasley, H. R., & Hoffland, E. (2023). Exploring options for increasing maize yields and grain Zn concentrations in sub-Saharan Africa. *Plant and Soil*, *488*(1), 625–636. https://doi.org/10.1007/s11104-023-05998-5

[8] Congreves, K. A., Hooker, D. C., Hayes, A., Verhallen, E. A., & Van Eerd, L. L. (2017). Interaction of long-term nitrogen fertilizer application, crop rotation, and tillage system on soil carbon and nitrogen dynamics. *Plant and Soil*, *410*(1), 113–127. https://doi.org/10.1007/s11104-016-2986-y

[9] Coskun, D., Britto, D. T., Shi, W., & Kronzucker, H. J. (2017). Nitrogen transformations in modern agriculture and the role of biological nitrification inhibition. *Nature Plants*, *3*(6), 17074. https://doi.org/10.1038/nplants.2017.74

[10] Drinkwater, L. E., Wagoner, P., & Sarrantonio, M. (1998). Legume-based cropping systems have reduced carbon and nitrogen losses. *Nature*, *396*(6708), 262–265. https://doi.org/10.1038/24376

[11] *FAOSTAT*. (n.d.). Retrieved May 11, 2025, from https://www.fao.org/faostat/en/#data/EM/visualize

[12] Freyer, B., & Bingen, J. (2021). Resetting the African Smallholder Farming System: Potentials to Cope with Climate Change. In N. Oguge, D. Ayal, L. Adeleke, & I. da Silva (Eds.), *African Handbook of Climate Change Adaptation* (pp. 1441–1467). Springer International Publishing. https://doi.org/10.1007/978-3-030-45106-6_267

[13] Giller, K. E., & Cadisch, G. (1995). Future benefits from biological nitrogen fixation: An ecological approach to agriculture. *Plant and Soil*, *174*(1), 255–277. https://doi.org/10.1007/BF00032251

[14] Girma, T., Biazin, B., Beyene, S., & Lemaga, B. (2020). Integrated Application of Organic and Blended Mineral Fertilizers Improves Potato Productivity and Income for Smallholder Farmers in Acidic Soils. *Environment and Natural Resources Research*, *10*(1), 61. https://doi.org/10.5539/enrr.v10n1p61

[15] Hochmuth, G., Mylavarapu, R., & Hanlon, E. (2014). *The Four Rs of Fertilizer Management*.

[16] Hu, Y., Li, D., Wu, Y., Liu, S., Li, L., Chen, W., Wu, S., Meng, Q., Feng, H., & Siddique, K. (2023). Mitigating greenhouse gas emissions by replacing inorganic fertilizer with organic fertilizer in wheat-maize rotation systems in China. *Journal of Environmental Management*, *344*, 118494. https://doi.org/10.1016/j.jenvman.2023.118494

[17] Jairus, O., Samuel, M., John, O., & Julie, L. (2021). Effect of phosphorus fortified compost on growth and yield of maize (Zea mays L.) and Lablab (Lablab purpureus L.) intercropped maize in acidic soils of Western Kenya. *African Journal of Agricultural Research*, *17*(2), 329–336. https://doi.org/10.5897/AJAR2020.15408

[18] Jin, J., Roland, B., Bing, H., Huang, J., Zhang, J., Wu, Y., Zhu, H., Wu, Y., & Chang, R. (2024). Nitrogen addition reduces soil phosphorus leaching in a subtropical forest of eastern Tibetan Plateau. *Applied Soil Ecology*, *202*, 105616. https://doi.org/10.1016/j.apsoil.2024.105616

[19] Kamau, J. W., Schader, C., Biber-Freudenberger, L., Stellmacher, T., Amudavi, D. M., Landert, J., Blockeel, J., Whitney, C., & Borgemeister, C. (2022). A holistic sustainability assessment of organic (certified and non-certified) and non-organic smallholder farms in Kenya. *Environment, Development and Sustainability*, *24*(5), 6984–7021. https://doi.org/10.1007/s10668-021-01736-y

[20] Kassaw, H., & Alemu, T. (2022). Morphological characterization of Desmodium dichotomum germplasm collected from eastern Amhara Ethiopia). *Journal of Rangeland Science*, *12*(2). https://doi.org/10.30495/rs.2022.682916

[21] Kihara, J. M., & Bolo, P. O. (2021). *Microbes matter: Unravelling trade-offs between integrated management options and microbial functions*. https://hdl.handle.net/10568/115527

[22] Kihara, J., Nziguheba, G., Zingore, S., Coulibaly, A., Esilaba, A., Kabambe, V., Njoroge, S., Palm, C., & Huising, J. (2016). Understanding variability in crop response to fertilizer and amendments in sub-Saharan Africa. *Agriculture, Ecosystems & Environment*, *229*, 1–12. https://doi.org/10.1016/j.agee.2016.05.012

[23] Macharia, J. M., Pelster, D. E., Ngetich, F. K., Shisanya, C. A., Mucheru-Muna, M., & Mugendi, D. N. (2020). Soil Greenhouse Gas Fluxes From Maize Production Under Different Soil Fertility Management Practices in East Africa. *Journal of Geophysical Research: Biogeosciences*, *125*(7), e2019JG005427. https://doi.org/10.1029/2019JG005427

[24] Mucheru-Muna, M. W., Ada, M. A., Mugwe, J. N., Mairura, F. S., Mugi-Ngenga, E., Zingore, S., & Mutegi, J. K. (2021). Socio-economic predictors, soil fertility knowledge domains and strategies for sustainable maize intensification in Embu County, Kenya. *Heliyon*, *7*(2). https://doi.org/10.1016/j.heliyon.2021.e06345

[25] Ndayisaba, P. C., Kuyah, S., Midega, C. A. O., Mwangi, P. N., & Khan, Z. R. (2021). Intercropping desmodium and maize improves nitrogen and phosphorus availability and performance of maize in Kenya. *Field Crops Research*, *263*, 108067. https://doi.org/10.1016/j.fcr.2021.108067

[26] Ndung'u, M., Ngatia, L. W., Onwonga, R. N., Mucheru-Muna, M. W., Fu, R., Moriasi, D. N., & Ngetich, K. F. (2021). The influence of organic and inorganic nutrient inputs on soil organic carbon functional groups content and maize yields. *Heliyon*, *7*(8), e07881. https://doi.org/10.1016/j.heliyon.2021.e07881

[27] Ntinyari, W., & Gweyi-Onyango, J. P. (2021). Greenhouse Gases Emissions in Agricultural Systems and Climate Change Effects in sub-Saharan Africa. In W. Leal Filho, N. Oguge, D. Ayal, L. Adeleke, & I. Da Silva (Eds.), *African Handbook of Climate Change Adaptation* (pp. 1–25). Springer International Publishing. https://doi.org/10.1007/978-3-030-42091-8_43-1

[28] Nziguheba, G., Zingore, S., Kihara, J., Merckx, R., Njoroge, S., Otinga, A., Vandamme, E., & Vanlauwe, B. (2016). Phosphorus in smallholder farming systems of sub-Saharan Africa: Implications for agricultural intensification. *Nutrient Cycling in Agroecosystems*, *104*, 321–340. https://doi.org/10.1007/s10705-015-9729-y

[29] Okalebo, J. R., Gathua, K. W., & Woomer, P. L. (2002). Laboratory Methods of Soil and Plant Analysis: A Working Manual. *Laboratory Methods of Soil and Plant Analysis: A Working Manual*.

[30] Palm, C. A., Gachengo, C. N., Delve, R. J., Cadisch, G., & Giller, K. E. (2001). Organic inputs for soil fertility management in tropical agroecosystems: Application of an organic resource database. *Agriculture, Ecosystems & Environment*, *83*(1), 27–42. https://doi.org/10.1016/S0167-8809(00)00267-X

[31] Richardson, A. E., & Simpson, R. J. (2011). Soil Microorganisms Mediating Phosphorus Availability Update on Microbial Phosphorus. *Plant Physiology*, *156*(3), 989–996. https://doi.org/10.1104/pp.111.175448

[32] Sahoo, S., Mukhopadhyay, P., Mowrer, J., Maity, P. P., Maity, A., Sinha, A. K., Sow, P., & Rakesh, S. (2022). Tillage and N-source affect soil fertility, enzymatic activity, and crop yield in a maize–rice rotation system in the Indian Terai zone. *Frontiers in Environmental Science*, *10*. https://doi.org/10.3389/fenvs.2022.983973

[33] Subbarao, G. V., Wang, H. Y., Ito, O., Nakahara, K., & Berry, W. L. (2007). NH4+triggers the synthesis and release of biological nitrification inhibition compounds in Brachiaria humidicola roots. *Plant and Soil*, *290*(1), 245–257. https://doi.org/10.1007/s11104-006-9156-6

[34] Taylor, E., & Tanumihardjo, S. (2010). Maize: A Paramount Staple Crop in the Context of Global Nutrition. *Comprehensive Reviews in Food Science and Food Safety*, *9*, 417–436. https://doi.org/10.1111/j.1541-4337.2010.00117.x

[35] Wanyonyi, T. N. (2023). *Tillage Effects on Selected Soil Properties and Rainfed Maize Growth in Upper Kabete Campus, University of Nairobi, Kenya* [Thesis, University of Nairobi]. http://erepository.uonbi.ac.ke/handle/11295/165066

[36] Zeyede, A. (2020). Optimization of the analytical method for the determination of organic matter. *Journal of Soil Science and Environmental Management*, *11*(1), 1–5. https://doi.org/10.5897/JSSEM2019.0784

[37] Zhang, F., & Li, L. (2003). Using competitive and facilitative interactions in intercropping systems enhances crop productivity and nutrient-use efficiency. *Plant and Soil*, *248*(1), 305–312. https://doi.org/10.1023/A:1022352229863

[38] Zhang, W., Cao, G., Li, X., Zhang, H., Wang, C., Liu, Q., Chen, X., Cui, Z., Shen, J., Jiang, R., Mi, G., Miao, Y., Zhang, F., & Dou, Z. (2016). Closing yield gaps in China by empowering smallholder farmers. *Nature*, *537*(7622), 671–674. https://doi.org/10.1038/nature19368

[39] Zhang, Z., Yan, J., Han, X., Zou, W., Chen, X., Lu, X., & Feng, Y. (2021). Labile organic carbon fractions drive soil microbial communities after long-term fertilization. *Global Ecology and Conservation*, *32*, e01867. https://doi.org/10.1016/j.gecco.2021.e01867

[40] Zhou, C., Jia, B., Wang, S., Huang, Y., Wang, Y., Han, K., & Wang, W. (2021). Effects of Nitrogen Fertilizer Applications on Photosynthetic Production and Yield of Japonica Rice. *International Journal of Plant Production*, *15*(4), 599–613. https://doi.org/10.1007/s42106-021-00156-2

[41] Zhou, M., Zhu, B., Wang, S., Zhu, X., Vereecken, H., & Brüggemann, N. (2017). Stimulation of N2 O emission by manure application to agricultural soils may largely offset carbon benefits: A global meta-analysis. *Global Change Biology*, *23*(10), 4068–4083. https://doi.org/10.1111/gcb.13648.

# The Terrestrial Hemiptera (Insecta) of the Amrabad Tiger Reserve, Telangana, India

Pradip Chandra Saha[1*]; Dhriti Banerjee[2]; M.E. Hassan[3]; Swetapadma Dash[4]; Susmita Khanra[5]; Rakhi Das[6]

[1,2,4,5,6]Zoological Survey of India, M-Block, New Alipore, Kolkata-700053, West Bengal, India
[3]Zoological Survey of India, Gangetic Plain Regional Centre, Patna- 800026
*Corresponding Author

Received:- 12 October 2025/ Revised:- 18 October 2025/ Accepted:- 23 October 2025/ Published: 31-10-2025
Copyright @ 2025 International Journal of Environmental and Agriculture Research
This is an Open-Access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (https://creativecommons.org/licenses/by-nc/4.0) which permits unrestricted Non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

***Abstract—*** *The Amrabad Tiger Reserve (ATR) in Telangana, India, represents a significant biodiversity hotspot within the Eastern Ghats. However, a comprehensive account of its insect fauna, particularly the order Hemiptera, has been lacking. This study presents the first systematic documentation of terrestrial hemipterans from ATR, based on faunistic surveys conducted from 2018 to 2020. A total of* ***58 species*** *belonging to* ***48 genera*** *and* ***18 families*** *were recorded, all representing first-time accounts from the reserve. The findings include species from both the Auchenorrhyncha and Heteroptera suborders. For each species, details on its distribution within India and globally are provided. This research establishes a crucial baseline for the hemipteran fauna of ATR, underscoring the reserve's ecological significance and providing essential data for future conservation and biogeographical studies.*

***Keywords— Auchenorrhyncha, Biodiversity, Eastern Ghats, Faunal Survey, Heteroptera, First Record, Amrabad Tiger Reserve.***

## I. INTRODUCTION

Hemiptera is fifth largest group, covering 8% of total proportions of global fauna of insect world. They are phytophagous, predators, hematophagous, omnivorous and also economically important beneficial as well as harmful and used in biological control, terrestrial, aquatic, even marine. Order Hemiptera include 4 suborders *viz.* Sternorrhyncha, Auchenorrhyncha, Colleorrhyncha and Heteroptera and comprises of about 1,02,183 species worldwide, of which about 6,479 species under 92 families have been reported from India (Distant, 1902, 1904, 1908, 1910, 1916, 1918; Chandra, 2012, 2013, Metcalf,1960). Suborder Auchenorrhyncha includes short-horned bugs, having antennae usually small and inconspicuous; when long, they appear slender and filamentous or two segmented (Chandra *et al*., 2012). Member of the suborder heteroptera can be recognised by having distinct head, angular region sclerotized and base of rostrum not touching anterior coxae. Wings are folded flat over the abdomen, forewing divided into a coriaceous anterior portion and a membranous posterior portion. Prabhakar (2013) studied distribution of species of the superfamily Coreoidea (Hemiptera) from different biogeographical areas including dry deciduous forest in India and reported 151 species under 59 genera. Pruthi (1936) studied on Indian Jassidae (Homoptera) and erected some new genera and species, with first records of some known species from India. About 42,347 species of Heteroptera are known all over the world (Henry, 2009, Mitra et al., 2016, Distant, 1902, 1904, 1908, Lis, 1999, Schuh, and Slater, 1995). Chandra *et al.* (2020) provided an account of Heteropteran bugs collected by light trap in and around Dum Dum, Kolkata; Biswas and Mitra (2010) provided a checklist of Indian Assassin Bugs; Mukhopadhyay (1988) studied Lygeidae from West Bengal and Sen (1994) documented hemipteran fauna of West Bengal.

This Tiger Reserve (ATR) is one of the largest tiger reserves in India that extends about 2611.4 Sq Km over Nagarkurnool and Nalgonda districts of Telangana Amrabad Tiger Reserve a well-known and well-preserved nature reserve in Nallamala Hills, part of the Eastern Ghats chain. This is the second-largest Tiger Reserve in terms of core area but the sixth-largest tiger reserve in terms of total area among 51 Tiger Reserves in India. The reserve was notified as a sanctuary in the year 1983 and after the bifurcation of Telugu States in 2014, it was declared as Amarabad Tiger Reserve. It lies in the three forest divisions of Amarabad, Achampet in Nagarkurnool district, and Nagarjunsagar division in Nalgonda district. Major reservoirs like the

Srishailam Dam and Nagarjunsagar Dam are fed by the river Krishna and its several perennial streams that originate in the Tiger Reserve. No consolidated information is available on fauna of hemipteran from ATR. Present study is based on 58 species under 48 genera belonging to 18 families of terrestrial hemipteran from the Amrabad Tiger Reserve, Telangana. All the species are recorded for the first time from the Tiger Reserve.

## II. MATERIALS AND METHODS

Bugs were collected during six faunistic surveys from 2018 to 2020 by the scientific teams of Zoological Survey of India in the Amrabad Tiger Reserve, Telangana. Hemipteran specimens were collected by using the light trap, insect net-sweep and hand picking methods and preserved in 70% alcohol. Images of specimens (<5mm) were taken by using Leica M205-A stereo zoom microscope and specimens (>5 mm) by Sony DSC-W55 Camera. Collected specimens were identified by comparing voucher specimens available in the National Zoological Collection and by the literature of Ananthasubramanian (1996), Distant (1902, 1904, 1908 1910,1916), Rider *et al*. (2002), Schuh and Slater (1995). Specimens were deposited to National Zoological Collections, Zoological Survey of India, Kolkata.

## III. FAUNAL DIVERSITY

### 3.1 Systematic list:

**Phylum** Arthropoda
**Class** Insecta
**Order** Hemiptera

**Suborder** Auchenorrhyncha

**Infraorder** Cicadomorpha

**Superfamily** Membracoidea

**Family I.** Cicadellidae

**Subfamily** Cicadellinae
**Genus 1.** *Cofana* Melichar, 1926
**1.** *Cofana spectra* (Distant, 1908)

**Subfamily** Deltocephalinae
**Genus 2.** *Exitianus* Ball, 1929
**2.** *Exitianus indicus* (Distant, 1908)
**Genus 3.** *Nephotettix* Matsumura, 1902
**3.** *Nephotettix virescens* (Distant, 1908)
**4.** *Nephotettix cincticeps* (Uhler, 1896)
**Genus 4.** *Bothrogonia* Melichar, 1926
**5.** *Bothrogonia ferruginea* (Fabricius, 1787)
**Genus 5.** *Neodartus* Melichar, 1903
**6.** *Neodartus scutellatus* Distant, 1908

**Tribe** Hecalini
**Genus 6.** *Thomsoniella* Signoret, 1879
**7.** *Thomsoniella albomaculata* Distant, 1908

**Superfamily** Cercopoidea

**Family II.** Aphrophoridae

**Subfamily** Aphrophorinae
**Tribe** Aphrophorini
**Genus 7.** *Poophilus* Stål, 1866
**8.** *Poophilus costalis* (Walker, 1851)
**Genus 8.** *Clovia* Stål, 1869

**9.** *Clovia puncta* (Walker, 1851)
**10.** *Clovia bipunctata* (Kirby, 1891)
**11.** *Clovia conifer* (Walker, 1851)

**Superfamily** Membracoidea

**Family III.** Membracidae

**Subfamily** Centrotinae
**Genus 9.** *Leptocentrus* Stål, 1866
**12.** *Leptocentrus leucaspis* (Walker, 1858)
**13.** *Leptocentrus taurus* (Fabricius, 1775)
**Genus 10.** *Tricentrus* Stål, 1866
**14.** *Tricentrus subangulatus* Distant, 1908
**15.** *Tricentrus congestus* (Walker, 1858)

**Family IV.** Lophopidae Stål, 1866

**Subfamily** Lophopinae
**Genus 11.** *Pyrilla* Stål, 1859
**16.** *Pyrilla perpusilla* (Walker, 1851)

**Suborder** Heteroptera

**Infraorder** Cimicomorpha

**Superfamily** Reduvioidea

**Family V.** Reduviidae

**Subfamily** Harpactorinae
**Genus 12.** *Polididus* Stål, 1858
**17.** *Polididus armatissimus* Stål, 1859
**Genus 13.** *Sycanus* Amyot & Serville, 1843
**18.** *Sycanus collaris* (Fabricius, 1781)

**Family VI.** Nabidae

**Genus 14.** *Nabis* Latreille, 1802
**19.** *Nabis capsiformis* Germar, 1837

**Superfamily** Miroidea

**Family VII.** Miridae

**Subfamily** Mirinae
**Genus 15.** *Charagochilus* Fieber, 1858
**20.** *Charagochilus longicornis* Reuter, 1884
**Genus 16.** *Proboscidocoris* Reuter, 1882
**21.** *Proboscidocoris capitatus* Distant, 1904
**Genus 17.** *Eurybrochis* Kirkaldy, 1902
**22.** *Eurybrochis politus* (Distant, 1909)

**Infraorder** Pentatomomorpha

**Superfamily** Pentatomoidea

**Family VIII.** Pentatomidae

**Subfamily** Pentatominae
**Tribe** Carpocorini
**Genus 18.** *Aeliomorpha* Stål, 1858
**23.** *Aeliomorpha lineaticollis* (Westwood, 1837)
**Tribe** Eysarcorini
**Genus 19.** *Eysarcoris* Hahn, 1834
**24.** *Eysarcoris montivagus* (Distant, 1902)
**25.** *Eysarcoris aenescens* (Walker, 1867)
**Genus 20.** *Carbula* Stål, 1864
**26.** *Carbula scutellata* Distant, 1887
**Genus 21.** *Harmolaus* Distant, 1902
**27.** *Harmolaus typicus* Distant, 1902
**Tribe** Halyini
**Genus 22.** *Halys* Fabricius, 1803
**28.** *Halys serrigera* Westwood, 1837
**Genus 23.** *Erthesina* Spinola, 1837
**29.** *Erthesina fullo* (Thunberg, 1783)
**Tribe** Nezarini
**Genus 24.** *Acrosternum* Fieber, 1860
**30.** *Acrosternum graminea* (Fabricius, 1787)
**Genus 25.** *Nezara* Amyot & Serville, 1843
**31.** *Nezara viridula* (Linnaeus, 1758)

**Superfamily** Coreoidea

**Family IX.** Coreidae

**Subfamily** Coreinae
**Tribe** Gonocerini
**Genus 26.** *Cletus* Stål, 1860
**32.** *Cletus bipunctatus* (Westwood, 1842)
**33.** *Cletus punctiger* (Dallas, 1852)
**34.** *Cletus punctulatus* (Westwood, 1842)
**Genus 27.** *Cletomorpha* Mayr, 1866
**35.** *Cletomorpha hastata* (Fabricius, 1787)
**Subfamily** Hydarinae
**Genus 28.** *Hydarella* Bergroth, 1925
**36.** *Hydarella orientalis* (Distant, 1902)

**Family X.** Alydidae

**Subfamily** Micrelytrinae
**Genus 29.** *Leptocorisa* Latreille, 1829
**37.** *Leptocorisa acuta* (Thunberg, 1783)
**Genus 30.** *Riptortus* Stål, 1860
**38.** *Riptortus linearis* (Fabricius, 1775)

**Family XI.** Rhopalidae

**Subfamily** Rhopalinae
**Genus 31.** *Liorhyssus* Stål, 1870
**39.** *Liorhyssus rubicundus* (Signoret, 1859)
**40.** *Liorhyssus hyalinus* (Fabricius, 1794)
**Subfamily** Serinethinae

**Genus 32.** *Leptocoris* Hahn, 1833
**41.** *Leptocoris augur* (Fabricius, 1781)

**Superfamily** Lygaeoidea

**Family XII.** Rhyparochromidae

**Subfamily** Rhyparochrominae
**Tribe** Rhyparochromini
**Genus 33.** *Elasmolomus* Stål, 1872
**42.** *Elasmolomus sordidus* (Fabricius, 1787)
**Genus 34.** *Metochus* Scott, 1874
**43.** *Metochus uniguttatus* (Thunberg, 1822)
**Genus 35.** *Dieuches* Dohrn, 1860
**44.** *Dieuches insignis* (Distant, 1904)
**Tribe** Myodochini
**Genus 36.** *Pseudopachybrachius* Malipatil, 1978
**45.** *Pseudopachybrachius guttus* (Dallas, 1852)
**Genus 37.** *Horridipamera* Malipatil, 1978
**46.** *Horridipamera nietneri* (Dohrn, 1860)
**Genus 38.** *Gyndes* Stål, 1862
**47.** *Gyndes pallicornis* (Dallas, 1852)
**Tribe** Lethaeini
**Genus 39.** *Neolethaeus* Distant, 1909
**48.** *Neolethaeus typicus* Distant, 1909

**Family XIII.** Lygaeidae

**Subfamily** Lygaeinae
**Genus 40.** *Spilostethus* Stål, 1868
**49.** *Spilostethus pandurus* (Scopoli, 1763)
**50.** *Spilostethus hospes* (Fabricius, 1794)
**Genus 41.** *Graptostethus* Stål, 1868
**51.** *Graptostethus servus* (Fabricius, 1787)
**Subfamily** Orsillinae
**Genus 42.** *Nysius* Dallas, 1852
**52.** *Nysius lacustrinus* Distant, 1909

**Family XIV.** Geocoridae

**Subfamily** Geocorinae
**Genus 43.** *Geocoris* Fallén, 1814
**53.** *Geocoris ochropterus* (Fieber, 1844)

**Family XV.** Oxycarenidae

**Genus 44.** *Oxycarenus* Fieber, 1837
**54.** *Oxycarenus laetus* Kirby, 1891

**Family XVI.** Blissidae

**Genus 45.** *Dimorphopterus* Stål, 1872
**55.** *Dimorphopterus gibbus* (Fabricius, 1794)

**Superfamily** Pyrrhocoroidea

**Family XVII.** Largidae

**Subfamily** Physopeltinae
**Genus 46.** *Physopelta* Amyot & Serville, 1843
**56.** *Physopelta schlanbuschii* (Fabricius, 1787)

**Family XVIII.** Pyrrhocoridae

**Subfamily** Pyrrhocorinae
**Genus 47.** *Dysdercus* Boisduval, 1835
**57.** *Dysdercus koenigii* (Fabricius, 1775)
**Genus 48.** *Euscopus* Stål, 1870
**58.** *Euscopus indecorus* (Walker, 1872)

### 3.2 Comparative analysis:

**TABLE 1**
**SYSTEMATIC ACCOUNTS AND DISTRIBUTION OF THE RECORDED HEMIPTERAN SPECIES FROM AMRABAD TIGER RESERVE OF TELANGANA.**

| Sl. No. | Name of the Species | Material Examined | Distribution in ATR Divisions | |
|---|---|---|---|---|
| | | | Amrabad | Achampet |
| | **Suborder Auchenorrhyncha** | | | |
| | **Infraorder Cicadomorpha** | | | |
| | **Superfamily Membracoidea** | | | |
| | **Family I: Cicadellidae** | | | |
| 1 | *Cofana spectra* (Distant, 1908) | 1 ex, Rangapur, 18.ix.2019, Deepa J. & Party | + | - |
| 2 | *Exitianus indicus* (Distant, 1908) | 1 ex, Uma Maheshwaram, 21.ix.2019, Deepa J. & Party | + | - |
| 3 | *Nephotettix virescens* (Distant, 1908) | 1 ex, Rangapur, 18.ix.2019, Deepa J. & Party | + | - |
| 4 | *Nephotettix cincticeps* (Uhler, 1896) | 1 ex, Rangapur, 18.ix.2019, Deepa J. & Party | + | - |
| 5 | *Bothrogonia ferruginea* (Fabricius, 1787) | 1 ex, Vatavarlapally, 10.ii.2020, Deepa J. & Party | + | - |
| 6 | *Neodartus scutellatus* Distant, 1908 | 1 ex, Pichakuntla Cheruvu, 24.xii.2018, Deepa J. & Party | + | - |
| 7 | *Thomsoniella albomaculata* Distant, 1908 | 1 ex, Rangapoor (Near Achampet), 29.xii.2018, Deepa J. & Party | - | + |
| | **Superfamily Cercopoidea** | | | |
| | **Family II: Aphrophoridae** | | | |
| 8 | *Poophilus costalis* (Walker, 1851) | 1 ex, B.K. Thirumalapur, 19.ix.2019, S.S. Jadhav & Party | + | - |
| 9 | *Clovia puncta* (Walker, 1851) | 2 exs, Octopus View Point, Domelpenta, 27.xii.2018, Deepa J. & Party | + | - |
| 10 | *Clovia bipunctata* (Kirby, 1891) | 1 ex, Rangapoor (Near Achampet), 29.xii.2018, Deepa J. & Party | - | + |
| 11 | *Clovia conifer* (Walker, 1851) | 1 ex, Vatavarlapally, 10.ii.2020, Deepa J. & Party | + | - |
| | **Superfamily Membracoidea** | | | |
| | **Family III: Membracidae** | | | |
| 12 | *Leptocentrus leucaspis* (Walker, 1858) | 1 ex, Vatavarlapally, 10.ii.2020; 1 ex, Pichakuntla Cheruvu, 24.xii.2018, Deepa J. & Party | + | - |

| | | | | |
|---|---|---|---|---|
| 13 | *Leptocentrus taurus* (Fabricius, 1775) | 1 ex, Pichakuntla Cheruvu, 24.xii.2018, Deepa J. & Party | + | - |
| 14 | *Tricentrus subangulatus* Distant, 1908 | 1 ex, Rangapur, 18.ix.2019, Deepa J. & Party | + | - |
| 15 | *Tricentrus congestus* (Walker, 1858) | 1 ex, Vatavarlapally, 10.ii.2020, Deepa J. & Party | + | - |
| | **Family IV: Lophopidae** | | | |
| 16 | *Pyrilla perpusilla* (Walker, 1851) | 1 ex, Vatavarlapally, 10.ii.2020; 1 ex, Near Loddimallavar Temple, 12.viii.2021, Deepa J. & Party | + | - |
| | **Suborder Heteroptera** | | | |
| | **Infraorder Cimicomorpha** | | | |
| | **Superfamily Reduvioidea** | | | |
| | **Family V: Reduviidae** | | | |
| 17 | *Polididus armatissimus* Stål, 1859 | 1 ex, Octopus View Point, Domelpenta, 27.xii.2018, Deepa J. & Party | + | - |
| 18 | *Sycanus collaris* (Fabricius, 1781) | 1 ex, Pichakuntlacheruvu, 24.xii.2018, Deepa J. & Party | + | - |
| | **Family VI: Nabidae** | | | |
| 19 | *Nabis capsiformis* Germar, 1837 | 3 exs, Pichakuntla Cheruvu, 24.xii.2018, Deepa J. & Party | + | - |
| | **Superfamily Miroidea** | | | |
| | **Family VII: Miridae** | | | |
| 20 | *Charagochilus longicornis* Reuter, 1884 | 2 exs, Boreddybovi (Near Vattavaralapally), 28.xii.2018, Deepa J. & Party | + | - |
| 21 | *Proboscidocoris capitatus* Distant, 1904 | 2 exs, Octopus View Point, Domelpenta, 27.xii.2018, Deepa J. & Party | + | - |
| 22 | *Eurybrochis politus* (Distant, 1909) | 1 ex, Uma Maheshwaram, 21.ix.2019, Deepa J. & Party | + | - |
| | **Infraorder Pentatomomorpha** | | | |
| | **Superfamily Pentatomoidea** | | | |
| | **Family VIII: Pentatomidae** | | | |
| 23 | *Aeliomorpha lineaticollis* (Westwood, 1837) | 2 exs, Pichakuntla Cheruvu, 24.xii.2018, Deepa J. & Party | + | - |
| 24 | *Eysarcoris montivagus* (Distant, 1902) | 1 ex, Vatavarlapally, 10.ii.2020, Deepa J. & Party | + | - |
| 25 | *Eysarcoris aenescens* (Walker, 1867) | 1 ex, Vatavarlapally, 10.ii.2020, Deepa J. & Party | + | - |
| 26 | *Carbula scutellata* Distant, 1887 | 1 ex, Rangapoor (Near Achampet), 29.xii.2018, Deepa J. & Party | - | + |
| 27 | *Harmolaus typicus* Distant, 1902 | 2 exs, Octopus View Point, Domelpenta, 27.xii.2018, Deepa J. & Party | + | - |
| 28 | *Halys serrigera* Westwood, 1837 | 1 ex, Pichakuntla Cheruvu, 24.xii.2018, Deepa J. & Party | + | - |
| 29 | *Erthesina fullo* (Thunberg, 1783) | 2 exs, Octopus View Point, Domelpenta, 27.xii.2018, Deepa J. & Party | + | - |
| 30 | *Acrosternum graminea* (Fabricius, 1787) | 2 exs, Boreddybovi (Near Vattavaralapally), 28.xii.2018, Deepa J. & Party | + | - |
| 31 | *Nezara viridula* (Linnaeus, 1758) | 2 exs, Boreddybovi (Near Vattavaralapally), 28.xii.2018, Deepa J. & Party | + | - |
| | **Superfamily Coreoidea** | | | |
| | **Family IX: Coreidae** | | | |

| | | | | |
|---|---|---|---|---|
| 32 | *Cletus bipunctatus* (Westwood, 1842) | 1 ex, Pichakuntla Cheruvu, 24.xii.2018; 1 ex, Vatavarlapally, 10.ii.2020, Deepa J. & Party | + | - |
| 33 | *Cletus punctiger* (Dallas, 1852) | 1 ex, Pichakuntla Cheruvu, 24.xii.2018, Deepa J. & Party | + | - |
| 34 | *Cletus punctulatus* (Westwood, 1842) | 1 ex, Rangapoor (Near Achampet), 29.xii.2018, Deepa J. & Party | - | + |
| 35 | *Cletomorpha hastata* (Fabricius, 1787) | 1 ex, B.K. Thirumalapur, 19.ix.2019, S.S. Jadhav & Party | + | - |
| 36 | *Hydarella orientalis* (Distant, 1902) | 2 exs, Lingamaiah Grassland Kunta, 13.ii.2020, Deepa J. & Party | + | - |
| | **Family X: Alydidae** | | | |
| 37 | *Leptocorisa acuta* (Thunberg, 1783) | 4 exs, Yellur, 20.ix.2019, Deepa J. & Party | + | - |
| 38 | *Riptortus linearis* (Fabricius, 1775) | 1 ex, Umamaheshwaram, 15.ii.2020, Deepa J. & Party | + | - |
| | **Family XI: Rhopalidae** | | | |
| 39 | *Liorhyssus rubicundus* (Signoret, 1859) | 1 ex, Pichakuntla Cheruvu, 24.xii.2018; 1 ex, Octopus View Point, 27.xii.2018, Deepa J. & Party | + | - |
| 40 | *Liorhyssus hyalinus* (Fabricius, 1794) | 1 ex, Pichakuntla Cheruvu, 24.xii.2018; 1 ex, Octopus View Point, 27.xii.2018; 1 ex, Uma Maheshwaram, 21.ix.2019, Deepa J. & Party | + | - |
| 41 | *Leptocoris augur* (Fabricius, 1781) | 1 ex, Pichakuntla Cheruvu, 24.xii.2018, Deepa J. & Party | + | - |
| | **Superfamily Lygaeoidea** | | | |
| | **Family XII: Rhyparochromidae** | | | |
| 42 | *Elasmolomus sordidus* (Fabricius, 1787) | 1 ex, Uma Maheswaram, 16.ix.2019, S.S. Jadhav & Party | + | - |
| 43 | *Metochus uniguttatus* (Thunberg, 1822) | 1 ex, Pichakuntla Cheruvu, 24.xii.2018, Deepa J. & Party | + | - |
| 44 | *Dieuches insignis* (Distant, 1904) | 1 ex, Vatavarlapally, 10.ii.2020, Deepa J. & Party | + | - |
| 45 | *Pseudopachybrachius guttus* (Dallas, 1852) | 1 ex, Vatavarlapally, 10.ii.2020, Deepa J. & Party | + | - |
| 46 | *Horridipamera nietneri* (Dohrn, 1860) | 1 ex, Octopus View Point, Domelpenta, 27.xii.2018, Deepa J. & Party | + | - |
| 47 | *Gyndes pallicornis* (Dallas, 1852) | 1 ex, Boreddybovi (Near Vattavaralapally), 28.xii.2018, Deepa J. & Party | + | - |
| 48 | *Neolethaeus typicus* Distant, 1909 | 1 ex, Uma Maheswaram, 16.ix.2019, S.S. Jadhav & Party | + | - |
| | **Family XIII: Lygaeidae** | | | |
| 49 | *Spilostethus pandurus* (Scopoli, 1763) | 1 ex, Uma Maheswaram, 16.ix.2019, S.S. Jadhav & Party | + | - |
| 50 | *Spilostethus hospes* (Fabricius, 1794) | 1 ex, Pichakuntla Cheruvu, 24.xii.2018, Deepa J. & Party | + | - |
| 51 | *Graptostethus servus* (Fabricius, 1787) | 1 ex, Pichakuntla Cheruvu, 24.xii.2018; 1 ex, Bhairapur, Mannanur, 18.iii.2019, S.S. Jadhav & Party | + | - |
| 52 | *Nysius lacustrinus* Distant, 1909 | 1 ex, Octopus View Point, Domelpenta, 27.xii.2018, Deepa J. & Party | + | - |
| | **Family XIV: Geocoridae** | | | |
| 53 | *Geocoris ochropterus* Fieber, 1844 | 1 ex, Pichakuntla Cheruvu, 24.xii.2018, Deepa J. & Party | + | - |
| | **Family XV: Oxycarenidae** | | | |

| | | | | |
|---|---|---|---|---|
| 54 | *Oxycarenus laetus* Kirby, 1891 | 1 ex, Uma Maheshwaram Temple, 21.ix.2019, Deepa J. & Party | + | - |
| | **Family XVI: Blissidae** | | | |
| 55 | *Dimorphopterus gibbus* (Fabricius, 1794) | 2 exs, Pichakuntlacheruvu, 24.xii.2018, Deepa J. & Party | + | - |
| | **Superfamily Pyrrhocoroidea** | | | |
| | **Family XVII: Largidae** | | | |
| 56 | *Physopelta schlanbuschii* (Fabricius, 1787) | 2 exs, Near Loddimallavar Temple, 12.viii.2021, Deepa J. & Party | + | - |
| | **Family XVIII: Pyrrhocoridae** | | | |
| 57 | *Dysdercus koenigii* (Fabricius, 1775) | 1 ex, Vatavarlapally, 10.ii.2020, Deepa J. & Party | + | - |
| 58 | *Euscopus indecorus* (Walker, 1872) | 1 ex, Octopus View Point, Domelpenta, 27.xii.2018, Deepa J. & Party | + | - |
| | **TOTAL** | | **54** | **4** |

***+ present; - absent;***

## IV. DISCUSSIONS

As compared to Sternorrhyncha (soft bodied bugs) and Auchenorrhyncha, Heteropteran bugs show adaptation to survive in warmer places with dry condition. Leathery forewings of as in most of the Heteropteran bugs. Among them members of the family of Reduviidae are most successful in arid and dry climate, as they learned to hide themselves under the stone and other similar objects to avoid desiccation during day time, and comes out when the temperature is suitable for predation. Present study is based on the mopping survey to Amrabad Tiger Reserve, Telangana, by the different survey parties during 2018-2020. This paper deals with 58 species under 48 genera belonging to 18 families of terrestrial bugs from the Amrabad Tiger Reserve, Telangana, with maximum number of species from Division of Amrabad. Family Pentatomidae, Rhyparochromidae and Cicadellidae were shown maximum diversity with 9 species, 7 species and 7 species respectively.

**TABLE 2**
**SHOWING SPECIES DISTRIBUTION IN DIFFERENT FAMILIES RECORDED FROM ATR**

| Sl.No. | Superfamily | Family | No. of species |
|---|---|---|---|
| **1** | Membracoidea | Cicadeliidae | 7 |
| **2** | | Aphrophoridae | 4 |
| **3** | | Membracidae | 4 |
| **4** | | Lophopidae | 1 |
| **5** | Reduvioidea | Reduviidae | 2 |
| **6** | | Nabidae | 1 |
| **7** | Mirioidea | Miridae | 3 |
| **8** | Pentatomoidea | Pentatomidae | 9 |
| **9** | Coreoidea | Coreidae | 5 |
| **10** | | Alydidae | 2 |
| **11** | | Rhophalidae | 3 |
| **12** | Lygaeoidea | Rhyparochromidae | 7 |
| **13** | | Lygaeidae | 4 |
| **14** | | Geocoridae | 1 |
| **15** | | Oxycarinidae | 1 |
| **16** | | Blissidae | 1 |
| **17** | Pyrrhocoroidea | Largidae | 1 |
| **18** | | Pyrrhocoridae | 2 |

## ACKNOWLEDGEMENTS

Authors express their sincere gratitude to the Director, Zoological Survey of India for providing all sorts of necessary facilities. Thanks are also due to Dr. Gurupada Mondal, Scientists E, Officer-in-charge, Entomology Division-B for his encouragements and guidance. Authors are thankful to staff members of Hemiptera Section and Library Section for their helpful co-operation in preparation of manuscript.

## REFERENCES

[1] Ambrose, Dunston P. 2006. A checklist of Indian Assassin Bugs (Insecta: Hemiptera: Reduviidae) with taxonomic status, Distribution and Diagnostic morphological characteristics. *Zoos Print Journal***, 21**(9):2388-2406**.**

[2] Ananthasubramanian, K. S. 1996. Fauna of India and the adjacent countries Homoptera: Membracidae. Zoological Survey of India, Kolkata, 534 pp.

[3] Biswas, B. and Mitra, B. 2010. A checklist of Indian Assassin Bugs (Insecta: Hemiptera: Reduviidae**).** *zsi.gov.in/checklist/reduviidae.pdf.*

[4] Chandra, K. 2013. Insect fauna of states and union territories in India. In, Arthropods and their Conservation in India (Insects and Spiders) (Eds. Uniyal, V: and Shrivastava Aseem). *ENVIS* Bulletin: Wildlife and Protected Areas. Wildlife Institute of India, Dehradun, **14** (1): 189-218.

[5] Chandra, K., Kushwaha S. 2012. Ghosh, M., Biswas, B. & Bal, A. Diversity of Grassland Auchenorrhyncha (Cicadidae, Cercopidae, Cicadellidae and Fulgoridae) In Madhya Pradesh and Chhattisgarh, India. *IJPAES*. 2(4), 257:263.

[6] Chandra, K., Saha, P. C., Biswas, B., Hassan, M. E., Praveen, K., Kushwaha, S., & Mukherjee, P. 2020. An Account of Heteropteran Bugs Collected by Light Trap in and Around Dum Dum (Kolkata), West Bengal. *Records of the Zoological Survey of India*, *120*(1), 65–83. https://doi.org/10.26515/rzsi/v120/i1/2020/119563.

[7] Distant, W. L. 1902. *The Fauna of British India, including Ceylon and Burma, Rhynchota*, 1:1-438.

[8] Distant, W. L. 1904. *Fauna Brit. India Including Ceylon and Burma, Rhynchota*, **2**:1-503.

[9] Distant, W. L. 1908. *The Fauna of British India, including Ceylon and Burma, Rhynchota,* Published by Taylor and Fransis London. **4**:1-501.

[10] Distant, W. L. 1910. *The Fauna of British India, including Ceylon and Burma, Rhynchota,* Published by Taylor and Fransis London. **5**: 1-210.

[11] Distant, W. L. 1916. *The Fauna of British India, including Ceylon and Burma, Rhynchota,* Published by Taylor and Fransis London. **4**:1-239.

[12] Distant, W.L. 1918. Rhynchota. Homoptera, Appendix, Heteroptera, Addenda. In: Shipley, A.E. & Marshall, G.A.K. (Eds.), *The Fauna of British India including Ceylon and Burma*. Vol. VII. Taylor & Francis, London, pp. viii+210.

[13] Henry, T. J. 2009. Biodiversity of Heteroptera in *Insect Biodiversity Science and Society*Edt. By Robert , G. Foottit and Piter, H. Adler. pp, 224-263.

[14] Lis, Jerzy. A.1999. Burrower bugs of the Old World- a catalogue (Hemiptera: Heteroptera: Cydnidae), Genus. Wroclaw.**10** (2):165-249.

[15] Metcalf, Z.P. 1960. *General catalogue of the Homoptera Fasc. VII, Cercopidae,* part 1, Machaerotidae Raigh N.L.: 1-616.

[16] Mitra, B. Roy, S., Biswas, O., Chakraborti, U. and Jehamalar, E. E. 2016. New records of aquatic bugs (Insecta: Hemiptera) from Sunderban biosphere reserve, West Bengal, India, Journal of Entomology and Zoology Studies, 4(4): 08-11.

[17] Mukhopadhyay, A. 1988. Taxonomic study of Lygeidae (Heteroptera: Insecta) from West Bengal (India). *Rec. Zool. Surv. India, Misc. Pub. Occ. Paper No*. 107: 1-72.

[18] Prabhakar, D. 2013. The Biogeographical distribution of species of the superfamily Coreidea Hemiptera in India, Rec. zool Serv. India, 113 (4): 103-128.

[19] Pruthi, H.S. (1936) Studies on Indian Jassidae (Homoptera). Part III. Descriptions of some new genera and species, with first records of some known species from India. Memoirs of the Indian Museum, 11, 101–131.

[20] Rider, D. A., Zheng, L.Y., and Kerzhner, I. M. 2002. Checklist and nomenclatural notes on the Chinese Pentatomidae (Heteroptera). II. Pentatominae. *Zoosyst Rossica*, **2**:135-153.

[21] Schuh, R.T and Slater, J.A, 1995. *True bugs of the World (Hemiptera: Heteroptera) Classification and Natural History, Cornell University press, Ithaca, USA.* 336 pp.

[22] Sen, G. C., Biswas, B. and Basu, R.C. 1994. *State Fauna Series 3: Fauna of West Bengal* (5): 433-447.

[23] Viraktamath, C.A. 2004. A revision of the deltocephaline leafhopper genus scaphoideus (Hemiptera: Cicadellidae) from the Indian subcontinent, *Zootaxa*, **578**: 1-48.

[24] Viraktamath, C.A. 2005. Key to the Subfamilies and Tribes of Leafhoppers (Hemiptera: Cicadellidae) of the Indian Subcontinent, *Bionotes*, **7**(1): 20-48.

# Micro Proteins: A Novel Approach for Crop Improvement

Dr. Sabitha. N[1*]; Bhavani Saiesha. C[2]; Narasimhulu. R[3]; Naga Madhuri K.V[4]; Reddi Sekhar. M[5]

Acharya N.G. Ranga Agricultural University, S.V. Agricultural college, Tirupati-517502
*Corresponding Author

Received:- 13 October 2025/ Revised:- 21 October 2025/ Accepted:- 26 October 2025/ Published: 05-11-2025
Copyright @ 2025 International Journal of Environmental and Agriculture Research
This is an Open-Access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (https://creativecommons.org/licenses/by-nc/4.0) which permits unrestricted Non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

***Abstract—*** *Microproteins (miPs) are small proteins, typically under 20 kDa, that play crucial roles in protein-protein interactions by forming non-functional complexes, thus regulating targets in a dominant-negative manner. They are classified into cis-miPs, which arise from mRNA isoforms through alternative splicing or translation, and trans-miPs, which evolve from genome amplification and domain loss. miPs can interact homotypically with similar domains or heterotypically with compatible but non-identical domains, potentially broadening their regulatory functions. Initially identified in mice, numerous miPs have since been discovered in plants, particularly through computational methods, although few have been functionally characterized, with a focus on Arabidopsis thaliana. Recent advances in synthetic microproteins have demonstrated their potential in crop engineering by modulating physiological processes. In plants, miPs have been linked to various functions, including epidermal cell patterning during root hair and trichome development, light responses, leaf development, pigment biosynthesis, and floral development. The identification and characterization of miPs in economically important plants have been facilitated by improved genomic and molecular tools, highlighting their significance in plant physiology and agricultural applications.*

***Keywords— Microproteins (miPs), Crop Improvement, Protein-Protein Interactions, Crop Engineering, Plant Development, Cis-miPs, Trans-miPs, Dominant-Negative Regulation, Synthetic Microproteins, Arabidopsis thaliana.***

## I. INTRODUCTION

Microproteins (miPs) are small proteins, typically ranging from 5 to 20 kDa, that play critical roles in plant growth and development by engaging in protein-protein interactions through a single domain (Kushwaha et al., 2022; Bs et al., 2023). The term 'microprotein' reflects their small size and negative regulatory properties, which are functionally analogous to microRNAs. miPs are thought to have evolved from gene duplications followed by domain loss, resulting in single-domain proteins that interact with and inhibit their multi-domain ancestral proteins (Straub et al., 2020). Consequently, miPs typically lack DNA-binding or activation domains and are unlikely to directly regulate transcription.

The first miP, a DNA binding inhibitor (Id) protein, was identified in mice as a 16 kDa helix-loop-helix (HLH) domain protein that inhibits the MyoD transcription factor to regulate muscle differentiation (Benezra et al., 1990). In plants, the LITTLE ZIPPER (ZPR) family was the first to be recognized as microproteins. Although TRYPTYCHON (TRY) was functionally characterized earlier, it was later classified as a miP due to its size and inhibitory function.

Microproteins are involved in a wide range of physiological processes, including metabolism, stress response, and the regulation of commercially vital traits like floral development and apical meristem maintenance. This positions both natural and synthetic miPs as powerful tools for crop bioengineering. With the advent of next-generation sequencing and advanced molecular tools, the discovery and characterization of miPs are accelerating, opening new avenues for agricultural innovation.

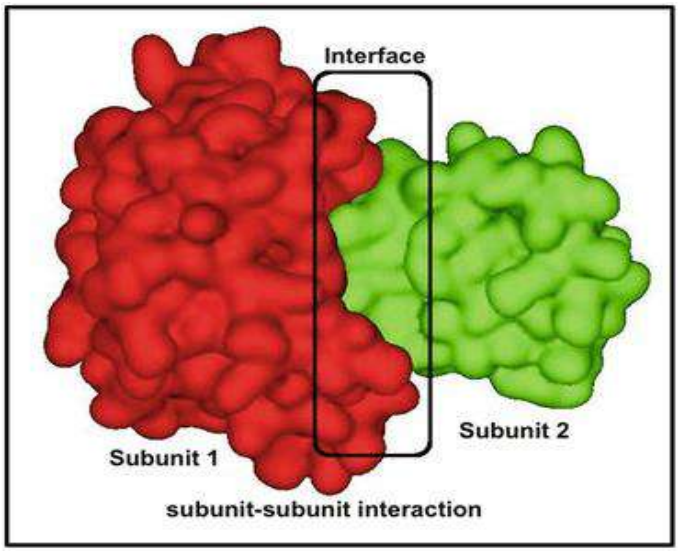



**FIGURE 1: Protein-miP interaction**

## II. CLASSIFICATION AND MECHANISM OF ACTION

### 2.1 Classification: Cis and Trans Microproteins:

MicroProteins are divided into two types based on their origin: cis and trans (Bs et al., 2023). **Cis-miPs** are encoded by mRNA, which is formed through alternative splicing and translation start and stop site selection. **Trans-miPs** originated as a result of genome amplification accompanied by domain loss.

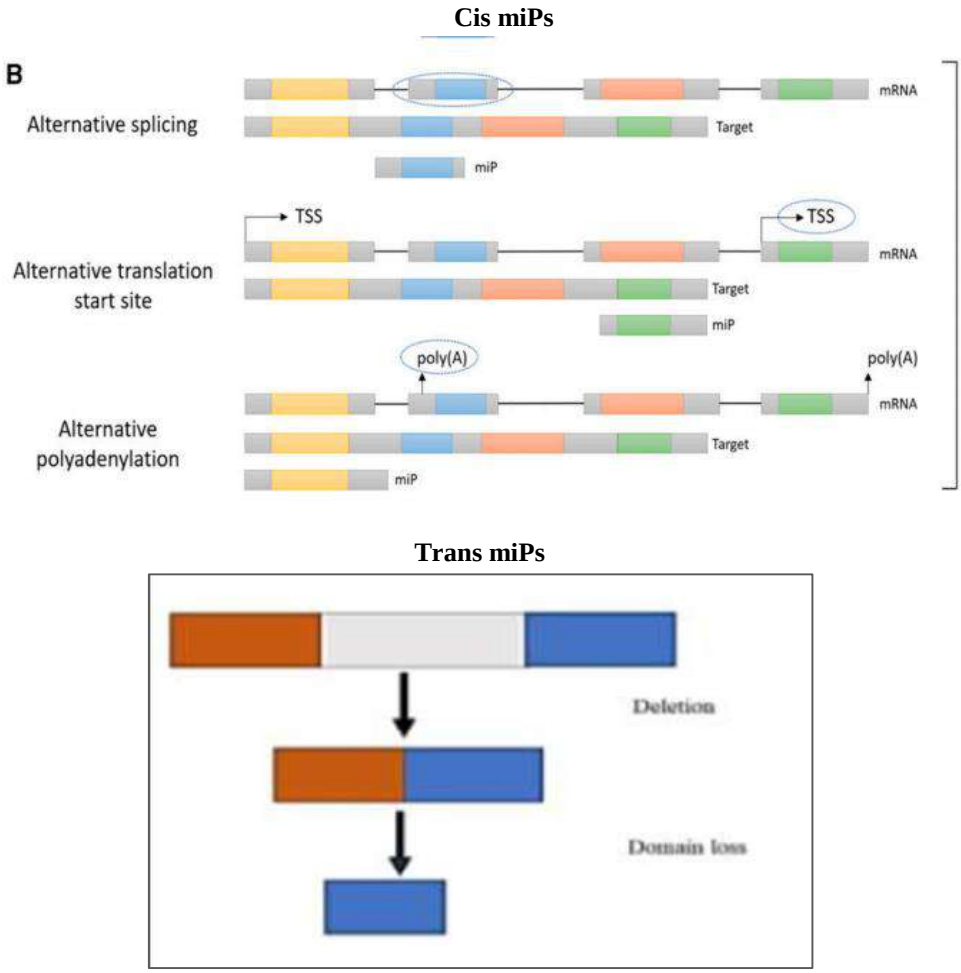



**FIGURE 2: Cis and Trans Microproteins**

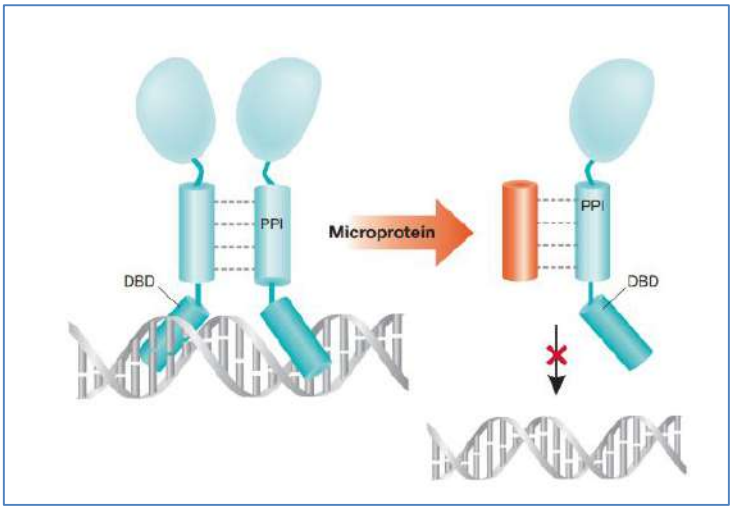



**FIGURE 3**

### 2.2 Modes of Protein Interaction:

Microproteins engage with domain proteins in two primary ways:

- **Homotypic Interactions:** In homotypic interactions, a microprotein (miP) connects with a protein that shares a similar domain. For instance, miP1a/b/BBX31/BBX30 interacts with CONSTANS and TOPLESS through the B-box motif to influence flowering.
- **Heterotypic Interactions:** In heterotypic interactions, a miP pairs with a non-identical yet compatible domain. An example of this is the B-box domain of miP1a/b interacting with the bHLH domain of PHYTOCHROME INTERACTING FACTOR (PIFs) and both the coiled-coil and C-terminal DNA binding domain of ETHYLENE INSENSITIVE 3 (EIN3), promoting photomorphogenic development. These heterotypic interactions may enable miPs to regulate targets that are evolutionarily unrelated, thereby expanding the potential functions of microproteins.

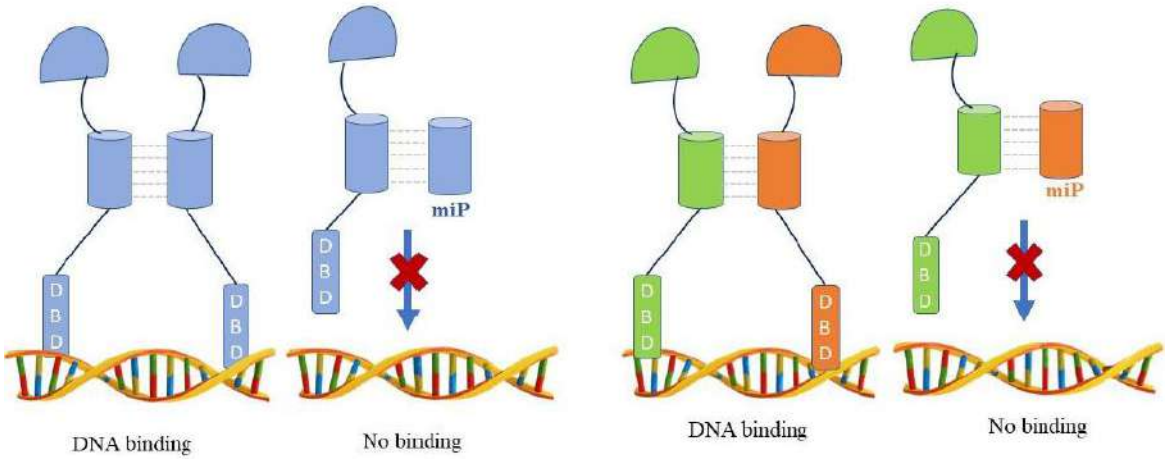



**FIGURE 4: Microproteins engage with domain proteins**

### 2.3 Mechanisms of Action:

Microproteins interfere with their targets by forming non-functional heterodimeric complexes that cannot bind to DNA. Their primary mechanisms include:

- **Receptor Inhibition:** Inhibiting receptors via binding them and making them inactive.
- **Transcriptional Regulation:** Binding to transcriptional factors and inhibiting them from binding to their promoters.
- **Transport Inhibition and Cytoplasmic Retention:** Inhibiting transport across membrane transporters or sequestering proteins in the cytoplasm.

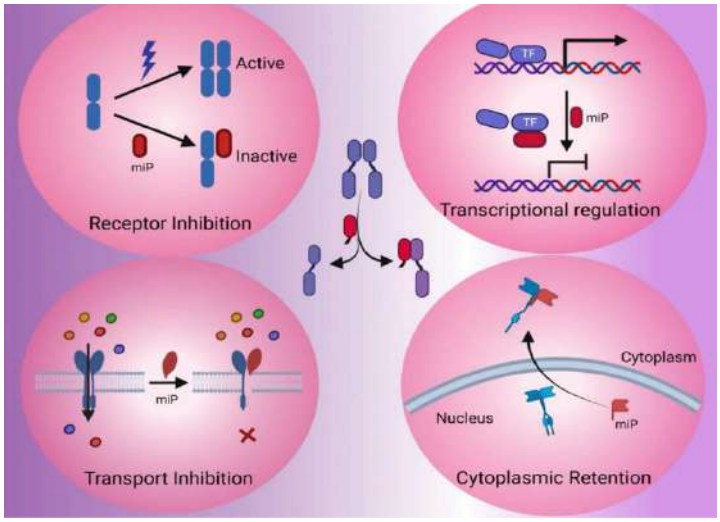



**FIGURE 5: Microprotein Inhibition through Non-Functional Heterodimeric Complexes**

## III. MAJOR MICROPROTEIN FAMILIES IN PLANTS

So far, microproteins (miPs) have been identified in the genomes of various plants, including *Arabidopsis*, rice, tomato, cotton, *Brachypodium*, and *Populus*. Notable examples of characterized microproteins include HLH, LITTLE ZIPPER (ZPR), KNATM, R3-MYB, MINI ZINC FINGER (MIF), and B-box miPs.

### 3.1 HLH miPs:

The first characterized miP was INHIBITOR OF DNA BINDING 1 (Id1), discovered in mice three decades ago. Id1 is an atypical basic helix-loop-helix (bHLH) protein featuring an HLH domain for protein interactions, but it lacks the adjacent basic domain essential for DNA binding. Id1 forms heterodimers with the bHLH transcription factor MyoD through its HLH domain, thus inhibiting MyoD's DNA binding to finely regulate muscle development (Benezra et al., 1990).

In *Arabidopsis*, there are 162 bHLH members, with 27 classified as atypical bHLH proteins due to their missing basic region or specific residues necessary for DNA binding. Among these, eight small proteins (92–129 amino acids) including PHYTOCHROME RAPIDLY REGULATED1 (PAR1) and PRE1/BANQUO1 (BNQ1) possess only one HLH domain and are identified as HLH miPs (Straub and Wenkel, 2017). These miPs are extensively studied, revealing two main functional modes: one where HLH miPs directly interact with bHLH TFs like Id1 to inhibit their DNA binding, and another where HLH miPs dissociate HLH suppressors to enhance bHLH TF activity. Interestingly, INCREASED LAMINA INCLINATION1 (OsILI1), a PRE1/BNQ1 homolog in rice, promotes brassinosteroid-induced cell elongation, influencing petiole cell growth and lamina joint inclination.

### 3.2 ZPR miPs:

ZPR miPs, such as ZPR1-4 (67 to 105 amino acids), are small proteins containing a leucine zipper (ZIP) domain, first identified in plants as miPs (Wenkel et al., 2007). The ZIP domain facilitates interaction between ZPR miPs and class III Homeodomain-Leucine Zipper (HD-ZIPIII) TFs. HD-ZIPIII activates ZPR gene expression, and ZPRs, in turn, repress the homodimerization and DNA binding of HD-ZIPIII proteins, creating a regulatory feedback loop for plant development, including shoot apical meristem and vascular development. Recently, the tomato ZPR gene product DEFECTIVE TOMATO MERISTEM (SlDTM) was shown to form a similar loop with HD-ZIPIII TF SlREV, which maintains stem cell balance (Xu et al., 2019). This ZPR miP-HD-ZIPIII feedback mechanism may be a conserved regulatory strategy in plant development.

### 3.3 MIF miPs:

MINI ZINC FINGER (MIF) miPs, including MIF1-3 (88 to 102 amino acids), contain a zinc finger domain that directly interacts with ZINC FINGER HOMEO DOMAIN (ZHD) TFs, inhibiting their DNA binding capabilities (Staudt and Wenkel, 2011; Eguen et al., 2015). For example, MIF1 prevents TF ZHD5 from binding DNA through direct interaction, influencing floral architecture and leaf development (Hong et al., 2011). Transgenic *Arabidopsis* plants expressing 35S::MIF1 exhibit significant developmental abnormalities and hormone insensitivity, indicating that MIF1 may target multiple proteins. In contrast, MIF2 and its tomato counterpart INHIBITOR OF MERISTEM ACTIVITY (SlIMA) interact with C2H2 zinc-finger

proteins, acting as adaptors to recruit co-repressors TOPLESS (TPL) and HISTONE DEACETYLASE19 (HDA19), forming a transcriptional repressor complex that suppresses downstream *WUS* and *SIWUS* gene expression in *Arabidopsis* and tomato, respectively (Bollier et al., 2018). Thus, MIF miPs likely regulate multiple targets through various mechanisms.

### 3.4 R3-MYB miPs:

R3-MYB miPs belong to the single-repeat R3 subfamily of MYB TFs. Seven R3-MYB miP members (77–112 amino acids) have been identified in *Arabidopsis*, including TRIPTYCHON (TRY) and TRICHOMELESS1 (TCL1) (Wang and Chen, 2014). These miPs contain a single MYB domain that mediates interactions with R/B-like bHLH TFs but lack a transcription activation domain (Zimmermann et al., 2004; Wang and Chen, 2014). An activator complex comprising a WD40-repeat protein, an R2R3 MYB-type TF, and a bHLH TF is crucial for initiating trichomes and root hairs. R3-MYB miPs compete with R2R3 MYB-type TFs for interaction with bHLH proteins, thereby negatively regulating trichome and root hair formation (Esch et al., 2003; Esch et al., 2004; Ishida et al., 2008). A cotton R3-MYB miP, GhCPC, has demonstrated a similar inhibitory role, interacting with bHLH protein GhMYC1 to suppress cotton fiber initiation and elongation (Liu et al., 2015).

### 3.5 KNATM miPs:

KNOTTED1-like homeobox (KNOX) and BEL1-like (BELL) are two classes of three-amino acid loop-extension (TALE) HD TFs in plants (Magnani and Hake, 2008). KNOX proteins interact with BELL proteins to form functional heterodimers that regulate petiole length. The KNATM miP (142 amino acids), which has a MEINOX domain but lacks a homeodomain, sequesters functional KNOX/BELL heterodimers (Magnani and Hake, 2008). In tomato, a KNATM miP called PETROSELINUM (PTS) similarly represses KNOX and BELL interactions, influencing leaf morphology and contributing to natural variation in leaf traits among Galapagean tomatoes.

### 3.6 B-box miPs:

B-box miPs, such as miP1a/BBX31 (121 amino acids) and miP1b/BBX30 (117 amino acids), contain a B-box domain. They were identified through *in silico* analysis of the *Arabidopsis* genome. These miPs interact with related B-box proteins CONSTANS (CO) and CONSTANS-like (COL) through their N-terminal B-box domain. They can also bind transcription co-repressors TPL and TPL-RELATED (TPR) via a short PF (V/L) FL motif at the C-terminus, recruiting TPL/TPR to CO to inhibit the expression of downstream *FLOWERING LOCUS T (FT)* genes (Graeff et al., 2016). Unlike typical DNA binding sequestration, B-box miP1a/b inhibit CO by serving as a bridge that integrates TFs and co-repressors into a transcriptional repressor complex. Recently, it was found that miP1a/b also directly targets PHYTOCHROME-INTERACTING FACTORS (PIFs) and ETHYLENE-INSENSITIVE 3 (EIN3) through their B-box domain. The interaction between miP1a/b and PIFs/EIN3 disrupts tetramer formation, repressing their DNA binding and transcriptional activities (Wu et al., 2020; Bhati et al., 2021). Consequently, B-box miPs exert their inhibitory effects by forming repressor complexes or disrupting the assembly of functional protein oligomers.

**TABLE 1**
**MICROPROTEINS FAMILY**

| Microprotein Family (Abbreviation) | Full Name / Description |
|---|---|
| **ZPR** | Little Zipper Proteins |
| **HLH** | Helix-Loop-Helix Proteins |
| **LNJ** | Little Ninja Proteins |
| **KNATM** | Knox Arabidopsis Thaliana Meinox Proteins |
| **Mip1a/b** | B-box Proteins |
| **PTRD** | Protein Tyrosine Phosphatase Receptor Type D |
| **MIFs** | Macrophage Migration Inhibitory Factors |

## IV. PHYSIOLOGICAL ROLES OF MICROPROTEINS IN PLANTS

Several MicroProteins belonging to different families have been identified in plants, primarily in *Arabidopsis*. Advancement of genomic and molecular tools has also led to the identification and characterization of miPs in plants of economic importance. These miPs have been characterized for a wide range of physiological functions.

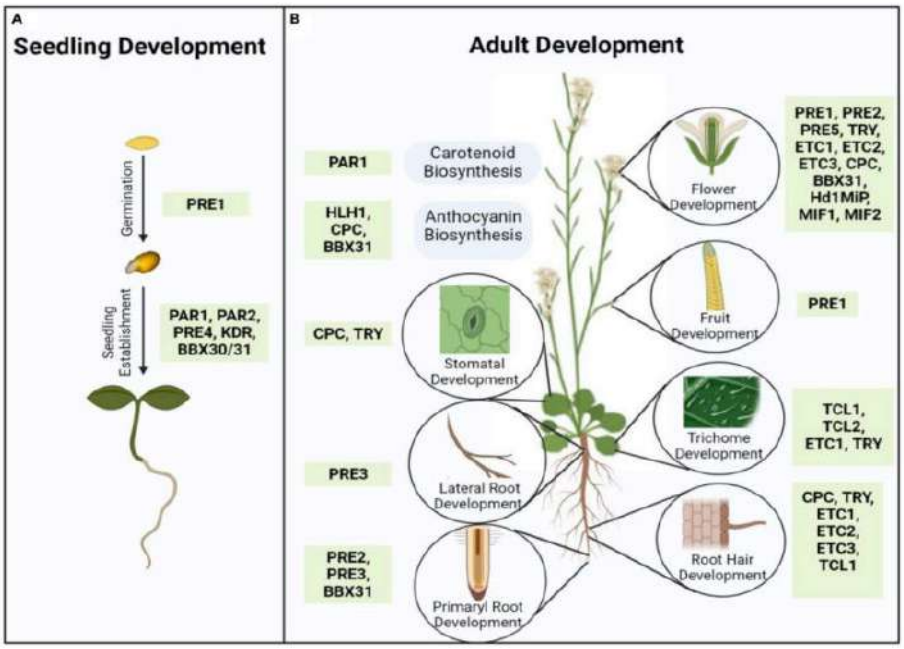



**FIGURE 6: Functional role of different microproteins from seedling to whole plant development**

**TABLE 2**
**LIST OF MICRO PROTEINS CHARACTERIZED IN ECONOMICALLY IMPORTANT PLANTS.**

| Micro Protein Family | Species | Known miPs | Targets | Function | References |
|---|---|---|---|---|---|
| Cis-microProteins | Brachypodium distachion | LNJ | NINJA | Shoot architecture | Hong et al., 2020 |
| NAC | Populus tomentosa | PtRD26IR | PtRD26 | Leaf senescence | Wang et al., 2021 |
| HLH | Oryza sativa | ILI1/PRE1 | IBH1 | Leaf inclination, cell elongation | Zhang et al., 2009a |
| Synthetic BBX | Oryza sativa | Hd1miP | HD1 | Flowering | Eguen et al., 2020 |
| ZPR | Solanum lycopersicum | SIDTM | HD-ZIPIII/REV | Stem cell homeostasis | Xu et al., 2019 |
| MIF | Solanum lycopersicum | SIMIA | SIKNU, TPL, HDA19 | Floral development, stem cell homeostasis | Bollier et al., 2018 |
| KNATM | Solanum lycopersicum | SIPTS | BIP | Leaf development | Kimura et al., 2008 |
| R3-MYB | Solanum lycopersicum | SITRY | SIGL3 | Trichome and root hair development, Anthocyanin biosynthesis | Tominaga-Wada et al., 2013 |
| R3-MYB | Gossypium spp. | GhCPC | MYC1, TTG1/4 | Cotton fiber elongation | Liu et al., 2015 |

### 4.1 Light-Mediated Responses:

Light is essential for plant growth and development. In darkness, seedlings exhibit skotomorphogenesis, characterized by elongated hypocotyls and closed cotyledons that form a hook-like structure known as the apical hook. Upon exposure to light, seedlings undergo photomorphogenesis, which involves the suppression of hypocotyl elongation and the opening and greening of cotyledons. ELONGATED HYPOCOTYL 5 (HY5) plays a central role in light signaling and photomorphogenesis, directly regulating the transcription of MICROPROTEIN 1A (miP1a) and B-BOX DOMAIN PROTEIN31 (BBX31) (13 kDa) under both white and UV light. While BBX31 regulates photomorphogenesis independently of miP1a and miP1b, both BBX proteins have a single B-box domain for protein interactions but lack the CCT domain needed for DNA binding. During the transition from dark to light, miP1a/b accumulate rapidly and interact with PIF3 and EIN3, disrupting their oligomerization and inhibiting their transcriptional activities.

Screening of activation-tagged mutants identified a mutant with elongated hypocotyls under continuous blue light, linked to a gene characterized as KIDARI (KDR), a member of the HLH miP family. KDR (10 kDa) specifically interacts with LONG HYPOCOTYL IN FAR-RED (HFR1), forming a heterodimer that sequesters HFR1 and releases PIFs from the HFR1-PIF heterodimer complex. Overexpression of MINI ZINC FINGER (MIF) miP, MIF1 (11 kDa), leads to various developmental defects, affecting chlorophyll levels, flowering, fertility, apical dominance, and longevity, as well as altering phytohormone sensitivity. However, transgenic plants did not show skotomorphogenic traits in darkness and were comparable to light-grown wild types, suggesting that MIF1 promotes photomorphogenesis and impacts certain adult developmental stages.

### 4.2 Shade Avoidance Response:

In shaded conditions, seedlings display shade avoidance responses characterized by hypocotyl elongation and altered photosynthetic pigment accumulation. Two shade-responsive HLH domain-containing miPs, PHYTOCHROME RAPIDLY REGULATED 1 (PAR1) and PAR2 (both 13 kDa), were identified from genomic data. Ectopic expression of these genes resulted in short hypocotyls, reduced cotyledon expansion, and increased chlorophyll and carotenoid levels, and dwarf, dark-green plants. The impaired shade avoidance response was linked to negative transcriptional regulation of a set of *SAUR* genes, which are inducible by hormones. Subsequent research showed that light stabilizes the PAR1 protein, which interacts through its HLH domain with PIF4, a key player in light signaling. This interaction inhibits PIF4-mediated transcriptional activation of downstream genes such as *PIL1*, *HFR1*, and *INDOLE-3-ACETIC ACID INDUCIBLE 29 (IAA29)*, leading to reduced hypocotyl length.

**FIGURE 7: Images of shade avoidance response in *Arabidopsis thaliana* and *Brassica rapa*.**

### 4.3 Leaf Development:

Leaves are the primary photosynthetic structures of plants, developing from pluripotent cells in shoot apical meristems with dorsoventral asymmetry. The adaxial surface of developing leaves faces the meristem, while the abaxial surface develops away from it. This polarity is crucial for proper leaf development, cellular specialization, and the formation of axillary meristems.

HD-ZIPIII proteins are key regulators of leaf development. Transcriptome profiling of seedlings with inducible HD-ZIPIII activity led to the identification of LITTLE ZIPPER (ZPR) proteins (ZPR1/2/3/4) (7–16 kDa), which directly interact with HD-ZIPIII/REV, inhibiting its DNA binding activity. Overexpression of ZPRs suppresses HD-ZIPIII/REV activity, establishing a negative feedback loop in their transcriptional regulation.

As a leaf develops from a primordium at the shoot apical meristem to a fully functional organ, it transitions from indeterminate to determinate growth, mediated by intrinsic developmental programs and environmental signals. MINI ZINC FINGER (MIF) is a 101-amino acid miP involved in leaf development, with 35S::MIF plants exhibiting pleiotropic developmental phenotypes indicative of involvement in various hormonal responses. Overexpression of MIF2 and MIF3 (coding for 9–10 kDa miPs)

results in smaller leaf sizes and abnormal expansion, suggesting a redundant role. While MIF proteins contain zinc finger domains, they lack other protein domains typically found in transcription factors, making them reliant on other factors for their activity. MIF1 interacts with Zinc Finger Homeo Domain 5 (ZHD5) to influence floral architecture and leaf development.

### 4.4 Hormone Signaling:

Shin-Young Hong et al. (2020) identified LITTLE NINJA, a microprotein related to NINJA that modulates Jasmonic Acid (JA) signaling by reducing the repression of JA responses. TOPLESS plays a role in auxin signaling but is also crucial in JA signaling, forming a complex with JAZ and NINJA. JA is recognized as a plant defense hormone. In the absence of JA, the JAZ/NINJA/TOPLESS complex interacts with transcription factors, converting them into repressors of gene expression. When JA is produced or applied, the CORONATINE INSENSITIVE 1 (COI1) JA receptor recruits a ubiquitin-SCF complex to degrade the JAZ repressor. This degradation relieves the repressive effects on transcription factors, allowing for the activation of JA-responsive genes.

Modulating JA signaling across various plant species has been linked to enhanced performance, including increased tolerance to salt and drought and greater resistance to pathogens and pests. Mutating multiple genes that encode JAZ repressor proteins has been shown to slow growth and reduce fertility, yet these plants exhibit improved resistance to pathogens. These findings support a model where JA balances defense and growth by altering central carbohydrate metabolism. The effects of LITTLE NINJA can be transferred between diverse cereal crops, making it a promising target for breeding. Overall, these results have important implications for understanding the complex regulation of JA-mediated transcription and its potential role in future crop enhancement.

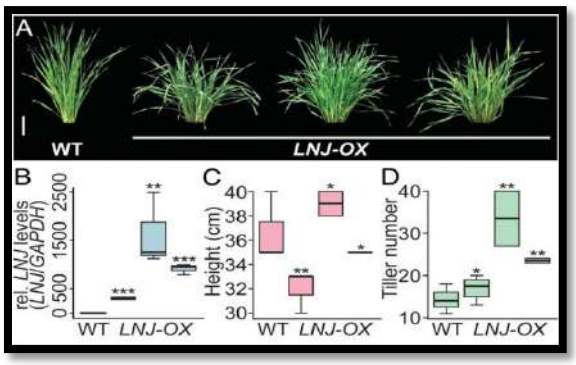



**FIGURE 8: LNJ influences shoot architecture in barley Wt. –Golden promise**

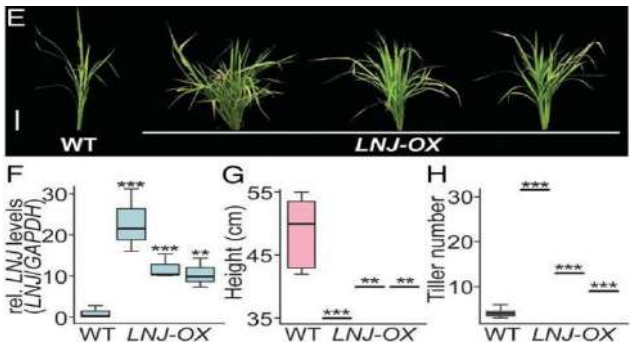



**FIGURE 9: LNJ influences shoot architecture in rice Wt. – Nippon bare**

### 4.5 Flowering:

The FLOWERING LOCUS T (FT) protein is the primary target of pathways that regulate flowering time. In the leaves of *Arabidopsis*, the appropriate day length triggers FT production, which then moves to the shoot apical meristem (SAM) and binds to the transcription factor FD, promoting the expression of genes necessary for the transition to flowering. The transcription factor CONSTANS (CO) plays a crucial role in the photoperiodic pathway that controls flowering. The production of CO transcripts and proteins occurs during the day. Under short-day conditions, CO does not accumulate enough to effectively promote FT in the leaves, restricting CO-dependent FT expression to long days.

CO's role in activating flowering is modulated through interactions with microproteins miP1a and miP1b. These microproteins serve as a "bridge," recruiting CO into a repressive complex that includes TOPLESS (TPL), thereby inhibiting CO's positive effect on flowering. A mutant that flowers at the same time as the wild-type Col-0 under long-day conditions was found to have a mutation in the JUMONJI 14 (JMJ14) gene. This indicates that miP1a represses flowering via JMJ14. JMJ14 encodes a histone demethylase responsible for demethylating histone H3 lysine 4 (H3K4), which has previously been shown to suppress flowering by inhibiting the expression of *FT* and floral identity genes. Supporting JMJ14's role as a floral repressor, the *jmj14-1* mutant flowers early even under short-day conditions.

## V. TECHNIQUES FOR MAPPING MICROPROTEINS IN PLANTS

The importance and versatility of microproteins highlight the need for effective methods to identify and characterize new microproteins. While microproteins are small proteins, not all small proteins qualify as microproteins, necessitating a

distinction between potential microproteins and other small proteins. This calls for a combination of approaches to identify possible microproteins and their targets. Due to the small size of microprotein genes, they may not be annotated in complex genomes, making their identification and characterization challenging. However, advancements in computational tools now facilitate the discovery of microprotein genes. Multi-omics approaches are being employed to uncover potential microproteins. Currently, high-throughput mass spectrometry, computational algorithms, and predictive protein tools are expected to streamline the process of identifying new microproteins.

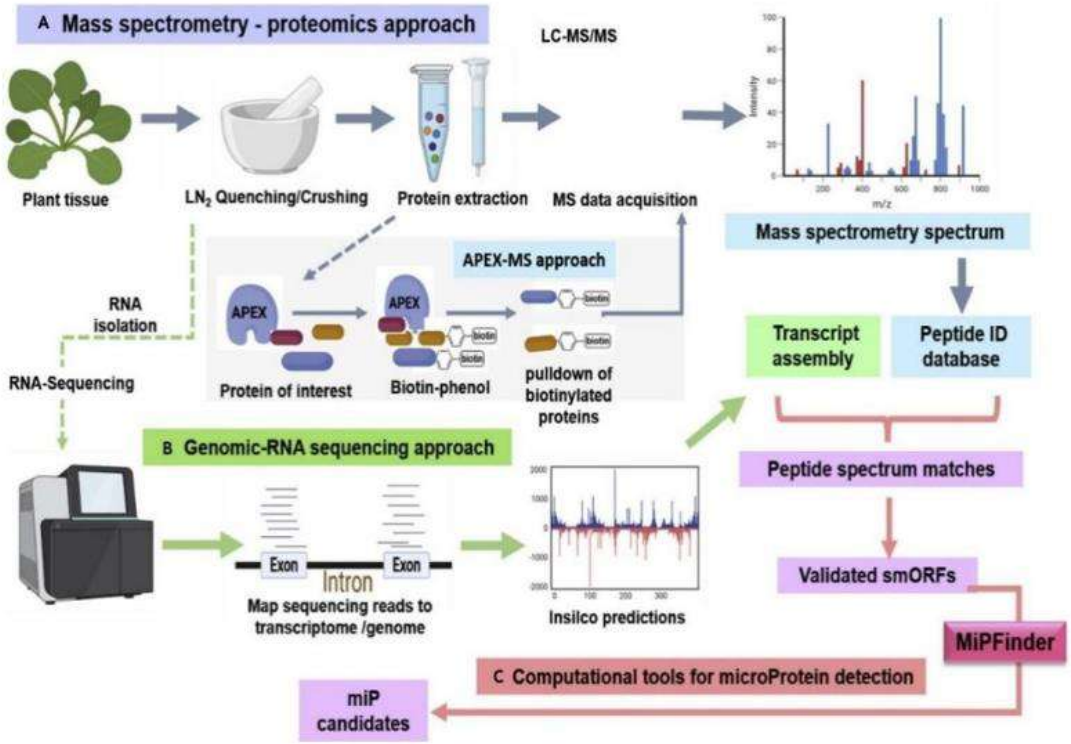



**FIGURE 10: Workflow for identification of MicroProteins in plants using biochemical, genomic, and computational tools.**

### 5.1 Mass Spectrometry-Based Proteomics Approach:

Chromatography techniques combined with mass spectrometry offer significant potential for characterizing small proteins. High-throughput proteomics, particularly using liquid chromatography-tandem mass spectrometry (LC-MS/MS), is commonly employed to identify small candidate peptides. In mass spectrometry methodologies, protein lysates are typically analyzed using shotgun and top-down proteomics approaches. Effective sample preparation is essential for detecting small proteins, focusing on proper denaturation, reduction, and digestion of protein samples. Solvents like methanol and acetone are often used to concentrate and purify target proteins. Although SDS-PAGE can also separate small proteins, it requires adjustments in the protocol to prevent the loss of these proteins during the process. This method can be adapted to analyze the fragmentation patterns of peptides, further aiding in their characterization.

### 5.2 Next-Generation Sequencing and Computational Tools:

Advancements in next-generation sequencing and modern algorithms have enabled the comprehensive analysis of genomic data, facilitating the discovery of novel microproteins. However, accurately classifying microproteins *in silico* remains challenging. The miPs Finder tool is a widely used method for filtering microproteins from small proteins. This computational tool requires several inputs, including annotated genomes, protein size, protein domains, evolutionary origins, and evidence of protein-protein interactions from existing databases to infer the potential functions of small proteins as microproteins. To gather this information, miP Finder relies on computational tools such as Python, BLAST, ClustalW2, hmmbuild, Pfam, and iPfam for multiple sequence alignment and annotation. In the context of plants, Gene Ontology (GO) functions are sourced from resources like Plant GO, agriGO, agriGOv2.0, GO Slim Viewer, GO Slim Set, AgBasev2.0, and PANTHER v11, which assist in the functional annotation of protein classes based on evolutionary relationships and the putative ancestors of microproteins.

Both computational methods and mass spectrometry can predict small open reading frames (smORFs) and potential microproteins. However, understanding the regulatory functions of microproteins often requires further insights and thorough experimental validation.

### 5.3 Functional Validation:

Observing the phenotypes of gain-of-function and loss-of-function mutants is an effective approach for characterizing their physiological roles. Analyzing different mutants of microprotein-coding genes can provide valuable information regarding their phenotypic, physiological, and regulatory characteristics. In biochemical methods, immunoprecipitation of FLAG-tagged microproteins is a common approach to identify their interacting partners, aiding in the understanding of their physiological functions. However, these methods can sometimes yield nonspecific interactions due to the small size of microproteins. A newer method involves *in situ* tagging using engineered ascorbate peroxidase 2 (APEX) to investigate microprotein-protein interactions. APEX tagging has been found to be more effective than traditional immunoprecipitation methods for microproteins, as it tends to produce fewer nonspecific interactors.

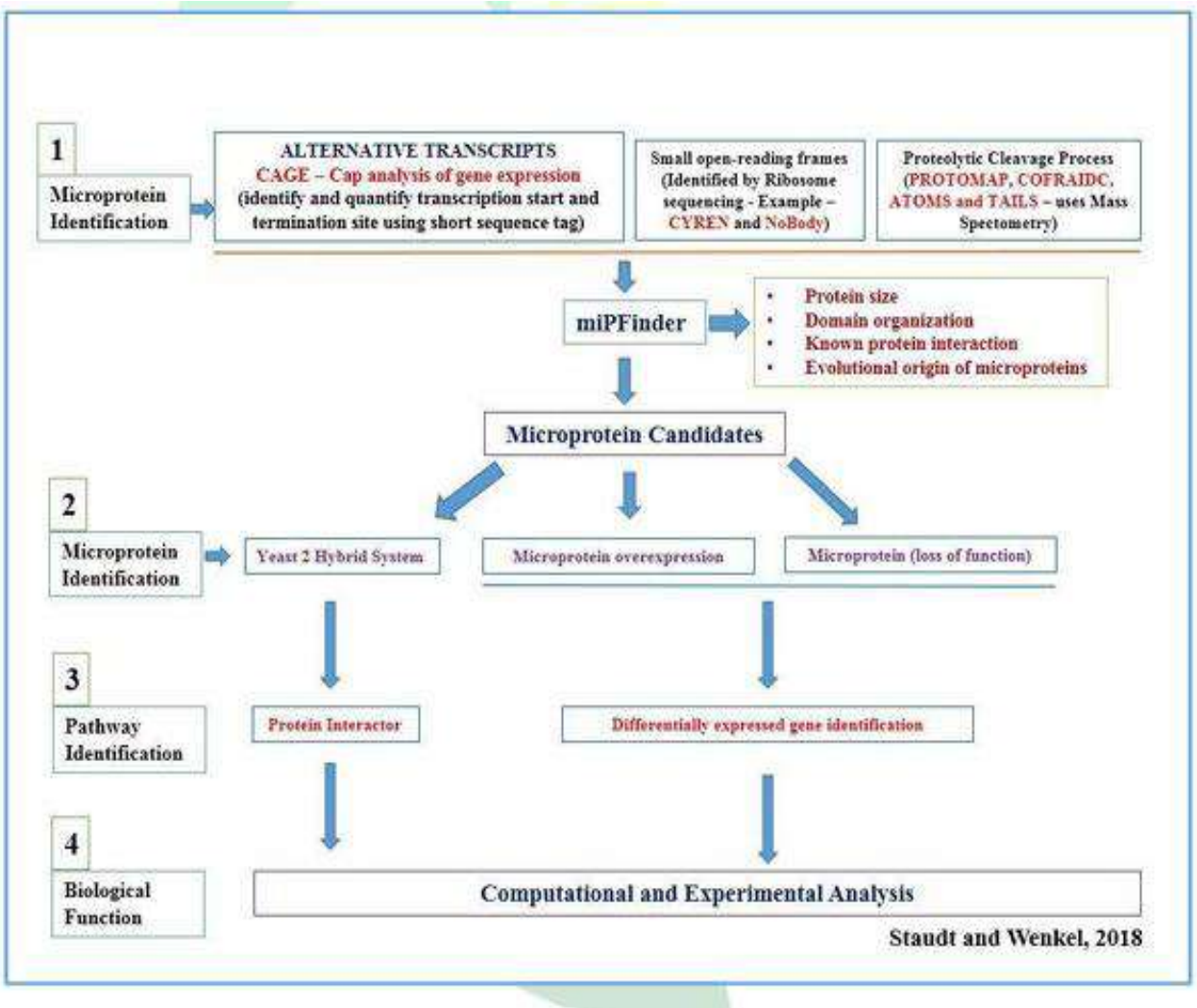



**FIGURE 11: Working with miP finder – a prominent approach for identification of microprotein**

## VI. LIMITATIONS

Determining the size limitation of microproteins raises questions about their role in controlling the formation of non-functional protein dimers and influencing their physiological outcomes. However, the homodimerization of microproteins remains uninvestigated. Currently, there is no evidence to suggest that microproteins can function non-cell autonomously. Most studies have focused on their dominant negative effects on target proteins, leaving their potential positive regulatory roles—such as stabilizing and enhancing the functionality of multimeric complexes—largely unexplored.

## VII. CONCLUSION AND FUTURE PERSPECTIVES

Food security faces increasing challenges due to climate change and unsustainable agricultural practices, highlighting the urgent need for sustainable and innovative solutions. Microproteins are crucial regulators of various physiological processes in plants. Their small size makes them ideal candidates for developing synthetic microproteins that could enhance plant stress resilience and improve productivity. Gaining a deeper understanding of the regulatory mechanisms of microproteins is essential for harnessing their potential as biotechnological tools in agriculture.

**Future Perspectives** include:

- **Identification and Characterization of Novel Microproteins:** As research continues, identifying novel miPs will be increasingly important. Their small size poses challenges for forward genetic screens, necessitating continued refinement of genomic, transcriptomic, and proteomic analyses.
- **Regulatory Specificity of Microproteins:** A key area of inquiry is understanding what determines the target specificity of microproteins and the pathways they influence, potentially involving temporal or spatial transcriptional regulation.
- **Microproteins as Biotechnological Tools:** Recent discoveries of miPs in crop genomes, such as SlIMA and SlDTM in tomatoes, and LNJ in *Brachypodium*, suggest their conserved roles. Since microproteins operate at the post-translational level, their functions depend on the balance between active and inactive protein complexes. This positions them as rapid and reversible regulators, offering exciting possibilities for biotechnological applications aimed at modifying specific traits in crops

## REFERENCES


[1] Benezra, R., Davis, R. L., Lockshon, D., Turner, D. L., & Weintraub, H. (1990). The protein Id: A negative regulator of helix-loop-helix DNA binding proteins. *Cell, 61*(1), 49–59. https://doi.org/10.1016/0092-8674(90)90214-y

[2] Bhati, K. K., Dolde, U., & Wenkel, S. (2021). MicroProteins: Expanding functions and novel modes of regulation. *Molecular Plant, 14*(5), 705–707. https://doi.org/10.1016/j.molp.2021.03.011

[3] Bollier, N., Sicard, A., Leblond, J., Latrasse, D., Gonzalez, N., Gévaudant, F., Benhamed, M., Raynaud, C., Lenhard, M., Chevalier, C., Hernould, M., & Delmas, F. (2018). At-MINI ZINC FINGER2 and Sl-INHIBITOR OF MERISTEM ACTIVITY, a conserved missing link in the regulation of floral meristem termination in Arabidopsis and tomato. *The Plant Cell, 30*(1), 83–100. https://doi.org/10.1105/tpc.17.00653

[4] Dolde, U., Rodrigues, V., Straub, D., Bhati, K. K., Choi, S., Yang, S. W., & Wenkel, S. (2018). Synthetic microproteins: Versatile tools for posttranslational regulation of target proteins. *Journal of Plant Physiology, 176*(4), 3136–3145. https://doi.org/10.1016/j.jplph.2018.09.001

[5] Eguen, T., Ariza, J. G., Brambilla, V., Sun, B., Bhati, K. K., Fornara, F., & Wenkel, S. (2020). Control of flowering in rice through synthetic microProteins. *Journal of Integrative Plant Biology, 62*(6), 730–736. https://doi.org/10.1111/jipb.12869

[6] Graeff, M., Straub, D., Eguen, T., Dolde, U., Rodrigues, V., Brandt, R., & Wenkel, S. (2016). MicroProtein-mediated recruitment of CONSTANS into a TOPLESS trimeric complex represses flowering in Arabidopsis. *PLOS Genetics, 12*(3), e1005959. https://doi.org/10.1371/journal.pgen.1005959

[7] Hong, S. Y., Sun, B., Straub, D., Blaakmeer, A., Mineri, L., Koch, J., Pedersen, B. H., Holme, I. B., Burow, M., Jørgensen, L. H. J., & Albà, M. M. (2020). Heterologous microprotein expression identifies LITTLE NINJA, a dominant regulator of jasmonic acid signaling. *Proceedings of the National Academy of Sciences, 117*(42), 26197–26205. https://doi.org/10.1073/pnas.2009539117

[8] Hong, S. Y., Kim, O. K., Kim, S. G., Yang, M. S., & Park, C. M. (2011). Nuclear import and DNA binding of the ZHD5 transcription factor is modulated by a competitive peptide inhibitor in Arabidopsis. *Journal of Biological Chemistry, 286*(2), 1659–1668. https://doi.org/10.1074/jbc.m110.167486

[9] Kushwaha, A. K., Dwivedi, S., Mukherjee, A., Lingwan, M., Dar, M. A., Bhagavatula, L., & Datta, S. (2022). Plant microProteins: Small but powerful modulators of plant development. *iScience, 25*(11), 105355. https://doi.org/10.1016/j.isci.2022.105355

[10] Staudt, A. C., & Wenkel, S. (2011). Regulation of protein function by 'microProteins'. *EMBO Reports, 12*(1), 35–42. https://doi.org/10.1038/embor.2010.196

[11] Wenkel, S., Emery, J., Hou, B. H., Evans, M. M. S., & Barton, M. K. (2007). A feedback regulatory module formed by LITTLE ZIPPER and HD-ZIPIII genes. *The Plant Cell, 19*(11), 3379–3390. https://doi.org/10.1105/tpc.107.055772.

# Sequential Hybrid Approach for Reliable Detection of Rainfall Pauses at the Beginning of the Rainy Season in Senegal: Towards a Predictive Tool for False Starts

Pape El Hadji Abdoulaye Gueye[1*]; Cherif Bachir Deme[2]; Diery Ngom[3]; Adrien Basse[4]

Department of TIC, UFR SATIC University Alioune Diop of Bambey, Bambey Senegal
*Corresponding Author : https://orcid.org/0009-0000-5222-3474

Received:- 13 October 2025/ Revised:- 24 October 2025/ Accepted:- 29 October 2025/ Published: 05-11-2025
Copyright @ 2025 International Journal of Environmental and Agriculture Research
This is an Open-Access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (https://creativecommons.org/licenses/by-nc/4.0) which permits unrestricted Non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

***Abstract—*** *This work focuses on the detection of false onsets of the rainy sea son in Senegal, a critical factor that can lead farmers, particularly smallholders, to initiate agricultural activities prematurely. Such errors, caused by misleading early rainfall events, result in yield losses and increase farmers' vulnerability to climate variability. Unlike existing methods, our approach incorporates statistical tests (such as Pettitt, Kendall, and Lombard) to enrich the input dataset with relevant change points related to rainfall, soil moisture, and vegetation. This enrichment step, combined with a formal detection of false onsets based on climatic, phenological, and statistical criteria, enhances the relevance, robustness, and contextualization of detection compared to purely statistical or physical approaches. In this context, a deep learning methodology was developed to identify false onsets at an early stage using multivariate climatic data. We designed a hybrid model combining LSTM, GRU, and multi-head attention layers to extract complementary representations of the input sequence. Model hyperparameters were optimized through Bayesian search to enhance detection performance. Results show consistent improvements across all key metrics: accuracy increased from 0.84 to 0.88, F1-score from 0.833 to 0.86, recall remained perfect at 1.0, precision rose from 0.767 to 0.81, and AUC improved from 0.900 to 0.92. These gains demonstrate the overall robustness of the optimized model, ensuring more reliable detection of false onsets*.

***Keywords— False onset, Deep learning, Statistical tests, LSTM, GRU, Attention, Bayesian optimization*.**

## I. INTRODUCTION

In semi-arid regions, particularly in the Sahel, agricultural drought—defined as a water deficit affecting crops and their productivity—constitutes a major risk to food security [1]. This region, and notably Senegal, is characterized by strong interannual rainfall variability [2], frequent delays in the onset of the rainy season, an extended dry season, and a continuous increase in land surface temperature (LST) [3, 4]. These climatic changes disrupt traditional agricultural cycles and increase the vulnerability of rainfed production systems.

A critical yet often overlooked phenomenon in this context is the **false onset of the rainy season**. It occurs as a series of weak initial rains—sometimes totaling about 20 mm over 2–3 days—followed by a dry spell. This sequence can create a false sense of security for farmers, who may sow prematurely, exposing their crops to early-season water stress that can significantly reduce yields. Despite extensive research on drought detection, the false onset—a key factor in shifting the rainfall calendar—has received relatively little attention, limiting the predictive capabilities of existing models [5]. Early detection is therefore essential to adjust sowing schedules, mitigate water stress risks, and support farmers' decision-making.

Recent advances in **remote sensing** and **machine learning** have greatly enhanced drought monitoring and forecasting. Remote sensing provides continuous spatio-temporal information despite the scarcity of in situ measurements [4]. Vegetation and soil moisture indices such as NDVI, VHI, LSWI, and SIF have been widely used to assess vegetation water stress [6–9]. Moreover,

composite indices integrating precipitation, temperature, and remote sensing data (e.g., CDI [10], SMADI [11], IDSI [12]) offer improved insights into drought dynamics.

In parallel, **machine learning** models have shown strong potential for drought and rainfall forecasting, particularly when combined with physical constraints that enhance predictive realism [9, 13]. Explainable Artificial Intelligence (XAI) techniques further highlight the relative importance of climatic variables, showing for example that temperature can be more influential than precipitation [1].

Within the **Sahelian context**, the timing of the rainy season is strongly influenced by large-scale climate phenomena such as ENSO. Some approaches, such as Kohonen maps, have been used to classify the onset and cessation of rainy seasons [5], while logistic regression models based on climate predictors (SST, precipitable water, dew point temperature, winds) have been proposed for seasonal onset forecasting [14]. However, these statistical models often show limited interregional transferability and struggle to capture complex intra-seasonal dynamics—particularly those linked to false starts.

To address these challenges, **recurrent neural networks (RNNs)** have been increasingly applied in hydrological and climatic studies. LSTM networks have proven effective for long-term temporal dependencies [15, 16], whereas GRU architectures better handle short-term fluctuations [20]. Transformer models, on the other hand, excel at capturing non-local relationships across long sequences. Hybrid architectures that integrate these models have recently emerged as a promising direction, leveraging heterogeneous data such as meteorological time series, soil properties, and remote sensing observations [18].

However, in West African contexts, the scarcity and heterogeneity of ground and satellite data remain a key limitation. Existing studies often overlook the **false onset phenomenon**, focusing instead on general drought indices or seasonal rainfall patterns. Statistical models alone lack the capacity for robust interregional generalization, while purely neural approaches may suffer from overfitting or reduced interpretability.

To overcome these limitations, this study proposes a **hybrid neural architecture combining LSTM, GRU, and Transformer components** for the detection and early prediction of false rainy season onsets in Senegal. The approach leverages multisource climatic and phenological data, enriched by statistical change-point detection tests (Pettitt, Kendall, Lombard) to identify structural shifts in rainfall, soil moisture, and vegetation dynamics. By integrating climatic, phenological, and statistical criteria, we define a **False Onset Index (FOI)** that enables more robust and realistic detection of false starts, improving the reliability of seasonal forecasts and supporting farmers in optimizing their sowing calendars.

The remainder of this paper is structured as follows: Section 2 describes the dataset, the LSTM–GRU–Transformer hybrid model, and hyperparameter optimization. Section 3 presents the results, including performance evaluation, robustness analysis, SHAP-based interpretability, and ablation studies. Section 4 also discusses the implications, limitations, and perspectives of the study, and Section 5 concludes by summarizing the main contributions.

## II. MATERIAL AND METHODS

It is a The data used in this study were compiled from multiple climatic and remote sensing sources covering the period 2000–2016 and harmonized into a consistent dataset. They include precipitation from CHIRPS (5 km), temperature, humidity, radiation, and wind from POWER-DAV (0.5°), soil moisture, evapotranspiration, and net radiation from FLDAS (25 km), as well as NDVI and land surface temperature (LST) from MODIS (1 km). In addition, large-scale climate indicators such as the Standardized Precipitation–Evapotranspiration Index (SPEI) and the Oceanic Niño Index (ONI) were incorporated. All variables were aggregated over Senegal and over the rainy season period to obtain representative annual values.

False onsets of the rainy season were automatically identified using relevant climatic criteria. Specifically, the variable *faux_demarrage* was set to 1 when cumulative precipitation exceeded 600 mm and the start of the season was too early (sos_doy < 145) or too late (sos_doy > 180), or when the month of July showed significant water stress, defined as SPEI_1_July < –1. Otherwise, *faux_demarrage* was set to 0. To enhance the robustness of the dataset, several statistical tests were applied to precipitation and temperature time series. The Pettitt test was used to detect abrupt change points in precipitation, the Lombard test to evaluate the influence of extreme values, and Kendall's tau to assess the association between temperature trends and false onsets. The outputs of these tests were added as auxiliary predictors, providing additional features for the learning model.

A hybrid deep learning model was developed by combining Long Short-Term Memory (LSTM), Gated Recurrent Unit (GRU), and Transformer components to capture the multi-scale temporal dynamics of the climatic data. The LSTM component was designed to model long-term dependencies, the GRU to represent short- and medium-term variability, and the Transformer to extract non-local relationships within sequences through multi-head attention. The outputs of these three branches were concatenated and passed through a dense layer with a sigmoid activation function to perform binary classification (false start or not). The model was trained using the Adam optimizer for stable convergence and balanced performance in terms of accuracy, recall, and F1-score.

Hyperparameter optimization was carried out using Bayesian search with *KerasTuner*, which iteratively updates a surrogate model (Gaussian Process) to balance exploration and exploitation during the search. Tuned parameters included the number of LSTM and GRU units, the number of Transformer heads and key dimensions, and the learning rate. The optimal configuration was obtained with 16 LSTM units, 48 GRU units, 2 attention heads, a key dimension of 4, and a learning rate of $2.04 \times 10^{-4}$. Cross-validation using 20% of the training set ensured model robustness and generalization. This optimized hybrid architecture leverages the complementarity of recurrent and attention mechanisms to improve early detection of false rainy season onsets, thereby supporting better agricultural decision-making and resilience to climate variability in the Sahel.

## III. RESULT AND DISCUSSION

### 3.1 Data Preparation:

The data come from our tabular dataset for false start detection, with *faux_demarrage* as the target variable and physical variables (such as PRECTOTCORR_SUM and T2M) as predictors. The data were normalized using a StandardScaler and split into training (80%) and test (20%) sets in a stratified manner to preserve a balanced distribution of positive and negative cases.

### 3.2 Static Cross-Validation Training:

A stratified 5-fold cross-validation (k = 5) was used to evaluate the model's generalization performance. In each iteration, the model was trained on k−1 folds and validated on the remaining fold, ensuring that each observation was used once for validation. Results indicate that after hyperparameter optimization, the model becomes both more accurate on average and more stable across folds.

### 3.3 Performance Evaluation:

The metrics used to assess the model allow evaluation of its relevance from multiple perspectives. Model performance shows improvement after hyperparameter optimization: accuracy increases from 84% to 88%, precision rises from 0.767 to 0.810, and the F1-score reaches 0.86 compared to 0.833 before optimization. Recall remains maximal (1.0), ensuring detection of all false start cases, which is essential to avoid operational errors. The AUC also improves slightly to 0.92, indicating enhanced overall discriminative ability. These results demonstrate greater robustness of the model across key metrics, confirming the effectiveness of hyperparameter optimization.

**TABLE 1**
**COMPARISON OF PERFORMANCE BEFORE AND AFTER HYPERPARAMETER OPTIMIZATION**

| Metric | Before Optimization | After Optimization |
|---|---|---|
| Accuracy | 0.84 ± 0.196 | 0.88 ± 0.160 |
| AUC | 0.900 ± 0.200 | 0.920 ± 0.180 |
| Precision | 0.767 ± 0.291 | 0.810 ± 0.250 |
| Recall | 1.000 ± 0.000 | 1.000 ± 0.000 |
| F1-score | 0.833 ± 0.211 | 0.860 ± 0.196 |

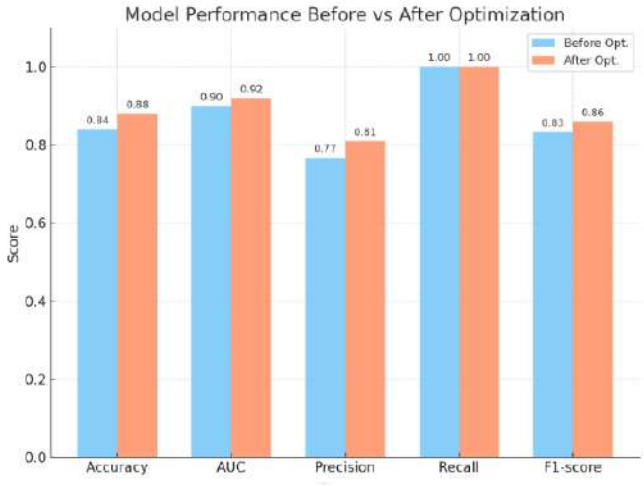



**FIGURE 1: Performance before and after optimization**

Performance improved after optimization: accuracy rose from 84% to 88%, precision from 0.767 to 0.810, F1-score from 0.833 to 0.86. Recall remains 1.0, ensuring all false start cases are detected. AUC also improved to 0.92.

### 3.4 Prediction Explanation (SHAP) and Robustness

To interpret the model, SHAP kernel values were computed on 100 test cases, with 30 bootstrap samples to ensure robustness. SHAP values identify the features with the greatest impact on predictions, while the mean and standard deviation highlight both their relevance and variability, which is crucial for model interpretation and improvement. Figure 2 shows that false starts are primarily influenced by recent hy 9 drological indicators. In particular, SPEI_1_July is the most important fea ture at the beginning of the season, with short-term indices (SPEI_1) having stronger effects than longer-term six-month indices. This highlights the pre dominance of immediate atmospheric conditions (June–July). Composite in dices such as SPEI are more relevant than raw precipitation (Rainf_f_tavg), confirming the effectiveness of synthetic water stress indicators. Global (oni) and phenological factors (sos_doy) have negligible influence, validating the predominance of local and recent causes

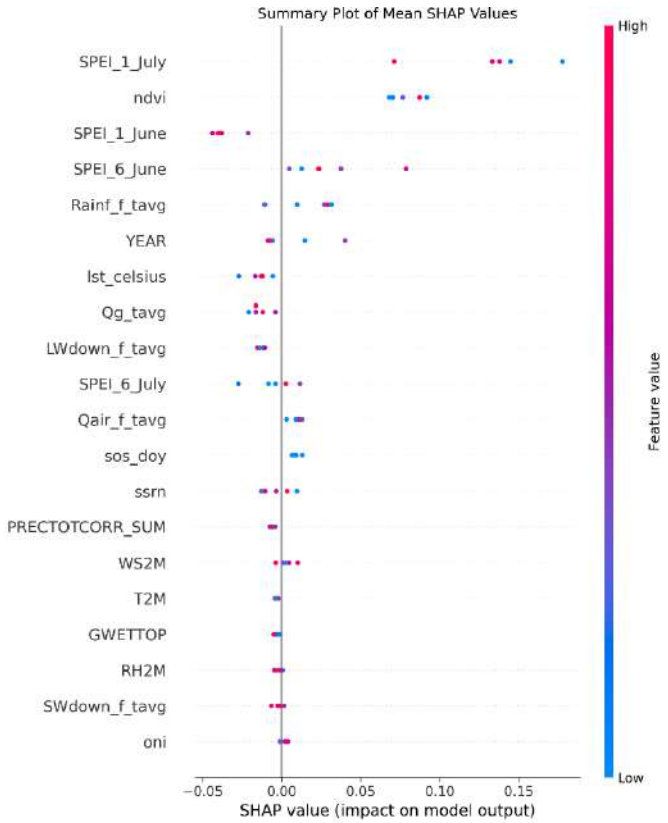



**FIGURE 2: Variable importance according to SHAP summary**

### 3.5 Robustness via Bootstrapping

To estimate the robustness or variability of SHAP values, 30 bootstrap samples were drawn from the test set, and SHAP values were computed for each sample. The mean and standard deviation of these values provide error bars and more reliable estimates. According to Figure 3, SPEI_1_July exhibits the highest mean SHAP value (+0.19), followed by PRECTOTCORR_SUM (+0.07). Both variables positively influence false starts during the rainy season. Bootstrapped SHAP confirms the robustness of these findings, while the relatively low standard deviation for the top features indicates consistent importance across resamples. This strengthens the understanding of underlying climatic mechanisms and provides confidence in model explanations.

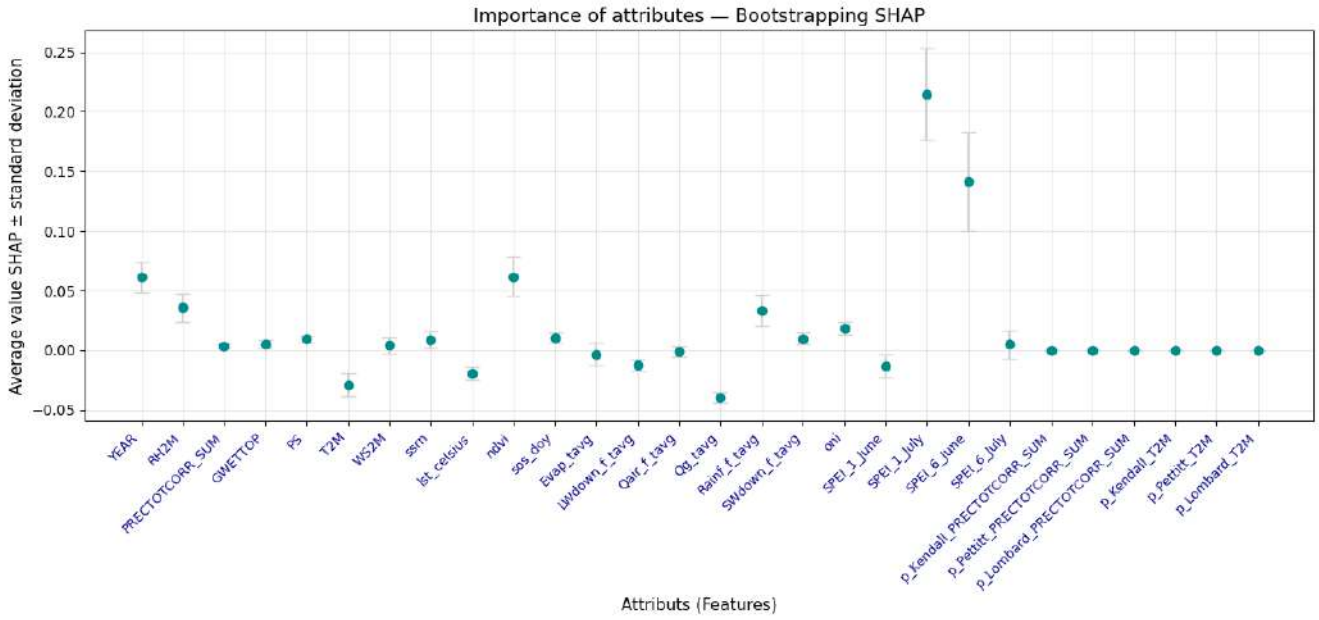



**FIGURE 3: Variability of SHAP values estimated via bootstrapping**

### 3.6 Performance Evaluation Based on Timestep

The time step determines the number of sequences used as model input to predict false starts.We varied this time step from 1 to 5 to assess its impact on model performance. Table 2 presents the mean accuracy, area under the ROC curve (AUC), precision, and F1-score (with standard deviation) across 5-fold cross-validation. According to Table 2, the model achieves the best performance in terms of Accuracy, AUC, Precision, andF1-score when the Timestep is 2. This highlights the importance of tuning this parameter to optimize the false start detection model.

**TABLE 2**
**PERFORMANCE OF THE LSTM + GRU + TRANSFORMER MODEL AS A FUNCTION OF THE TIMESTEP**

| Timestep | Accuracy (mean ± std) | AUC (mean ± std) | Precision (mean ± std) | F1-score (mean ± std) |
|---|---|---|---|---|
| 1 | 0.84 ± 0.196 | 0.900 ± 0.200 | 0.767 ± 0.291 | 0.833 ± 0.211 |
| 2 | 0.88 ± 0.160 | 0.920 ± 0.180 | 0.810 ± 0.250 | 0.860 ± 0.196 |
| 3 | 0.86 ± 0.120 | 0.910 ± 0.170 | 0.800 ± 0.240 | 0.850 ± 0.190 |
| 4 | 0.85 ± 0.140 | 0.905 ± 0.180 | 0.795 ± 0.230 | 0.845 ± 0.200 |
| 5 | 0.83 ± 0.150 | 0.890 ± 0.190 | 0.780 ± 0.250 | 0.830 ± 0.210 |

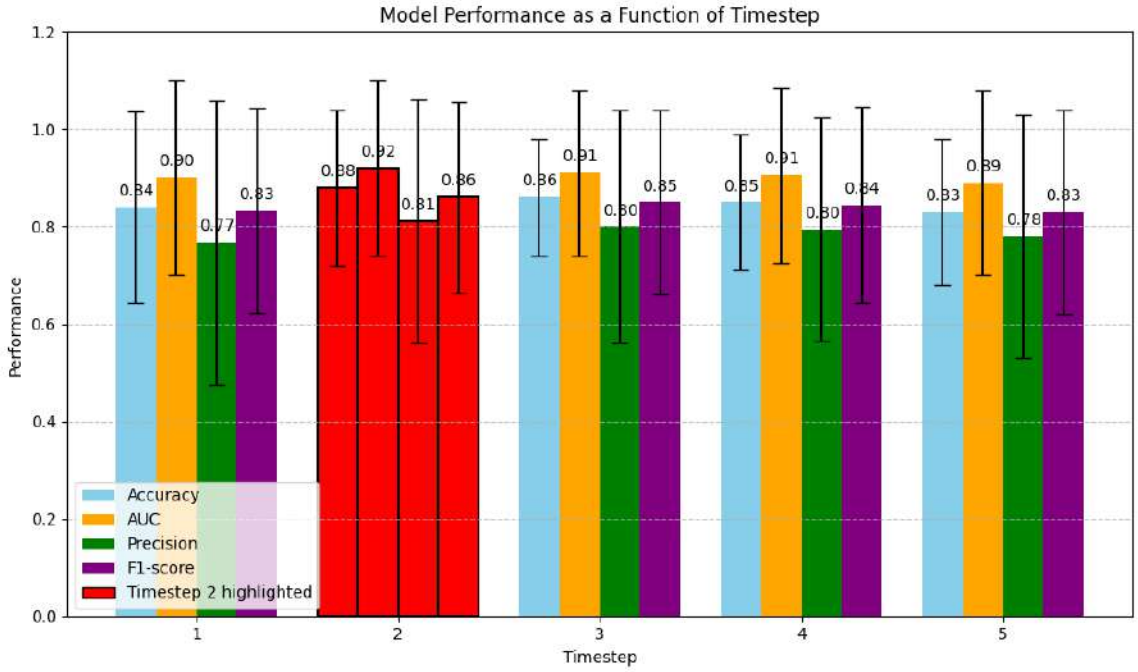



**FIGURE 4: Selection of the optimal timestep for the hybrid model**

Best performance occurs at Timestep = 2.

### 3.7 Ablation Study of the Hybrid Model:

To evaluate the individual contribution of the model components in predicting false starts of the rainy season, we conducted an ablation study analyzing the impact of each component on the achieved performance.

**TABLE 3**
**ABLATION STUDY OF THE HYBRID MODEL. VALUES REPRESENT MEAN AND STANDARD DEVIATION OVER 5-FOLD CROSS-VALIDATION**

| Model | Accuracy | AUC | F1-score |
|---|---|---|---|
| LSTM only | 0.84 ± 0.196 | 0.90 ± 0.20 | 0.767 ± 0.291 |
| LSTM + GRU | 0.88 ± 0.16 | 0.92 ± 0.18 | 0.81 ± 0.25 |
| LSTM + Transformer | 0.86 ± 0.12 | 0.91 ± 0.17 | 0.80 ± 0.24 |
| GRU + Transformer | 0.85 ± 0.14 | 0.905 ± 0.18 | 0.795 ± 0.23 |
| Full (LSTM + GRU + Transformer) | 0.88 ± 0.16 | 0.92 ± 0.18 | 0.86 ± 0.196 |

### 3.8 Justification of Performance

The full hybrid model (LSTM + GRU + Transformer) outperforms partial models (LSTM only, LSTM + GRU, LSTM + Transformer, GRU + Trans former) in terms of Accuracy, AUC, and F1-score. LSTM alone partially captures long-term dependencies. Adding GRU improves selective memory, enhancing recall and F1-score. Integrating the Transformer introduces an attention mechanism that helps identify critical time points, improving AUC. The combination LSTM + GRU + Transformer fully leverages the LSTM's sequential representation, the GRU's selective memory, and the Transformer's multi-head attention, providing a robust representation of the data for detecting false starts during the rainy season. We now compare our results with previous studies and present limitations and future perspectives in the following section.

## IV. DISCUSSION

### 4.1 Main Results:

The study confirms the effectiveness of a hybrid model combining LSTM, GRU, and multi-head attention for detecting false starts of the rainy season. Bayesian optimization improved performance: Accuracy increased from 84% to 88%, F1-score from

0.79 to 0.86, and recall from 0.9 to 1.0. These results demonstrate that the model effectively detects all cases of false starts, which is crucial for preventing premature sowing. Across all experiments (see Table 3), the model achieved a mean accuracy of 0.88±0.16, a mean AUC of 0.92±0.18, and a mean F1-score of 0.86±0.196.

### 4.2 Comparison with Existing Methods:

Compared to traditional methods such as the Composite Drought Index (CDI) or SMADI, our hybrid approach integrates phenological, climatic, and statistical criteria (Pettitt and Kendall tests), as well as the temporal patterns of precipitation. This allows for a more precise and context-aware detection of false starts, outperforming physical or purely statistical models that struggle to handle climate variability and the multidimensionality of the data. In comparison with recent approaches:

• The IRD model [14], although effective, is limited by the lack of attention mechanisms and low scalability. Our approach integrates multi source sequences and provides a robust and interpretable solution adapted to Sahelian environments.

• The satellite-based approach by Balti et al. [16] focuses on global drought indices. Our model, by specifically targeting false rainfall starts, adds local value for agricultural planning.

• The model by Ichi et al. [15], based on CAMELS, addresses global hydrological dynamics. Our architecture, optimized for low-resource environments, stands out with fine temporal granularity suited to Sahelian dynamics.

• The Scisimple approach [17] focuses on global seasonal forecasts. Our model complements this work by anticipating short and localized events, which are critical for agricultural decision-making.

• The reference model by Agudelo et al. [18] demonstrates solid performance for predicting USDM categories. In contrast, our approach specifically targets false starts, events absent from these categories, achieving robust performance across 5-fold cross-validation. Overall, our hybrid model outperforms partial configurations (LSTM alone, LSTM+GRU, etc.) and stands out for its ability to handle the complexity and local variability of the Sahelian climate

### 4.3 Limitations:

Despite the overall improvement in all metrics, certain limitations remain. The complexity of the hybrid model (LSTM + GRU + Transformer) can lead to longer training times and sensitivity to hyperparameter choices. Furthermore, the reliance on the quality and resolution of climate data may affect the robustness of predictions under extreme or unprecedented conditions. These points highlight the need for continuous monitoring and field validation to ensure operational reliability.

### 4.4 Future Perspectives:

To further enhance the performance and robustness of the model, efforts should focus on increasing and diversifying the data (including field observations and high-resolution time series), performing field validation to compare predictions with real-world observations, adapting the model regionally to specific climatic and agronomic conditions, and enabling real-time deployment through early warning platforms for farmers and decision-makers. These strategies will maximize the operational applicability and agronomic relevance of false start detection.

## V. CONCLUSION

This work demonstrated the effectiveness of a hybrid model combining LSTM, GRU, and multi-head attention for detecting false starts of the rainy season. Bayesian hyper-parameter optimization significantly improved all key metrics, including accuracy, F1-score, and AUC, ensuring reliable and comprehensive detection of critical events. SHAP value analysis enhanced the understanding of the respective contributions of climatic variables, reinforcing the model's transparency and robustness. Despite limitations related to the quality and spatial resolution of the data used, this hybrid approach outperforms traditional methods and shows promising potential for operational deployment as a decision-support tool for agricultural stakeholders. Finally, this work highlights the importance of a continuous improvement approach, based on integrating higher-resolution data and thorough field validation. These steps are essential to optimize the agronomic impact of the model and strengthen the resilience of agricultural systems in the face of increasing climate variability.

## ACKNOWLEDGEMENT

This research did not receive any external funding. The corresponding author personally covered all related expenses.

## CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

## DATA AVAILABILITY STATEMENT

The data used and/or analyzed during this study are available from the corresponding author upon reasonable request. additionally, the source code associated with this work is hosted in a private github repository (papegu). interested researchers or students can contact the corresponding author to request access. Upon request, access will be granted by inviting the requester as a collaborator on the github repository, allowing them to download and use the code for their own research or study purposes.

## AUTHOR CONTRIBUTIONS STATEMENT

The corresponding author, pape elhadji abdoulaye gueye, conducted all aspects of the research, from study design to manuscript writing. the co-authors, provided guidance, oversight, and final approval of the work.

## REFERENCES

[1] Muhammad Rasool Al-Kilani, Jawad Al-Bakri, Michel Rahbeh, Cody Knutson, Tsegaye Tadesse, and Qasem Abdelal. Agricultural drought assessment in data-limited arid regions using opensource remotely sensed data: A case study from Jordan. 156(2):89.

[2] Pape ElHadji Abdoulaye Gueye, Cherif Bachir Deme, and Adrien Basse. Improved climate risk assessment tool: Integration of satellite data and machine learning models for climate prediction on farmland around the senegal river. Mathematical Modelling of Engineering Problems., 12(5):1513–1523, May 2025.

[3] Mouhamadou Sylla, Michel Nikiema, Peter Gibba, Ibourahima Kebe, and Nana Ama Browne Klutse. Climate Change over West Africa: Re cent Trends and Future Projections. pages 25–40, apr 2016.

[4] Nesrine Farhani. Contribution of Remote Sensing and Auxiliary Vari ables in the Study of the Evolution of Drought Periods. PhD thesis, Université Paul Sabatier- Toulouse III and Université de Carthage (Tunisia), February 2022.

[5] Faye Dioumacor, F Kaly, Abdou Lahat Dieng, Dahirou Wane, Cheikh Modou Noreyni Fall, and Amadou Gaye. Prediction of the Onset and Offset of the Rainy Season in Senegal Using Kohonen Self-Organizing Maps.

[6] Trisha Bhaga, Munyaradzi Shekede, and Cletah Shoko. Impacts of Climate Variability and Drought on Surface Water Resources in Sub Saharan Africa Using Remote Sensing: A Review. 12:4184.

[7] Kassahun Tenebo Alito, Mulu Sewinet Kerebih, and Dawit Asregedew Hailu. Characterization of Drought Detection With Remote Sensing Based Multiple Indices and SPEI in Northeastern Ethiopian Highland. 18:11786221251328833.

[8] Zhaoxu Zhang, Wei Xu, Zhenwei Shi, and Qiming Qin. Establishment of a comprehensive drought monitoring index based on multisource re mote sensing data and agricultural drought monitoring. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 14:2113–2126, 2021.

[9] Hao Chen, Ni Yang, Xuanhua Song, Chunhua Lu, Menglan Lu, Tan Chen, and Shulin Deng. A novel agricultural drought index based on 15 multi-source remote sensing data and interpretable machine learning. 308:109303.

[10] Zakari Seybou Abdourahamane, Issa Garba, Aboubakr Gambo Boukary, and Alisher Mirzabaev. Spatiotemporal characterization of agricultural drought in the Sahel region using a composite drought in dex. 204:104789.

[11] Alzira Gabrielle Soares Saraiva Souza, Alfredo Ribeiro Neto, and Laio Lucas de Souza. Soil moisture-based index for agricultural drought assessment: SMADI application in pernambuco state-brazil. 252:112124, 2021.

[12] Rajkumar Guria, Manoranjan Mishra, Richarde Marques da Silva, and Carlos Antonio Costa dos Santos. Multisensor Integrated Drought Sever ity Index (IDSI) for assessing agricultural drought in Odisha, India. 37:101399.

[13] Mikhael G. Alemu and Fasikaw A. Zimale. Integration of remote sensing and machine learning algorithm for agricultural drought early warning over Genale Dawa river basin, Ethiopia. 197(3):243.

[14] Seyni Salack, Koufanou Hien, Namo K. Z. Lawson, Inoussa Abdou Saley, Jean-Emmanuel Paturel, and Moussa Waongo. Prévisibilité des faux départs de saison agricole au sahel. In Risques climatiques et agriculture en Afrique de l'Ouest, pages 31–43. IRD Éditions, 2025. Consulté en août 2025.

[15] 500daysofAI. Prédire les inondations et la sécheresse avec l'ia, 2025. Synthèse d'un article NeurIPS 2019 sur les LSTM appliqués aux bassins versants via le jeu de données CAMELS.

[16] Hanen Balti, Raja Inoubli, Ali Ben Abbes, and Riadh Farah. Prédiction de la sécheresse à partir des images satellitaires : une approche à base d'apprentissage profond. In Actes de la conférence TAIMA 2022, 2022.

[17] Simple Science. Exploiter l'apprentissage automatique pour prédire les pluies saisonnières en afrique de l'est, 2025. Consulté en août 2025. Résumé d'une étude sur l'utilisation de LASSO et Elastic Net pour la prévision pluviométrique saisonnière en Afrique de l'Est.

[18] Julian Agudelo, Vincent Guigue, Cristina Manfredotti, and Hadrien Piot. Prévision de sécheresse en utilisant une architecture neuronale 16 hybride intégrant des séries temporelles et des données statiques. In Conférence hébergée de l'AFIA, 2025.

[19] Sepp Hochreiter and Jürgen Schmidhuber. Long Short-Term Memory. Neural Comput., 9(8):1735–1780, nov 1997. [20] Krzysztof Zarzycki and Maciej Ławryńczuk. Advanced predictive control for gru and lstm networks. Information Sciences, 616:229–254, 2022.

# Physiological Screening of Foxtail Millet Genotypes for Water-Use Efficiency and Yield under Rainfed Conditions

D. Venkatesh Babu[1*]; T. Raghavendra[2]; Y. S. Satish Kumar[3]

[1,2]Scientist, Crop Physiology, Regional Agricultural Research Station, ANGRAU, Nandyal 518502
[3]Scientist, Soil Science, Regional Agricultural Research Station, ANGRAU, Nandyal 518502
*Corresponding Author

Received:- 14 October 2025/ Revised:- 21 October 2025/ Accepted:- 28 October 2025/ Published: 05-11-2025
Copyright @ 2025 International Journal of Environmental and Agriculture Research
This is an Open-Access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (https://creativecommons.org/licenses/by-nc/4.0) which permits unrestricted Non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

***Abstract—*** *A field experiment was conducted during kharif 2015 to assess water-use efficiency (WUE) traits and yield potential of foxtail millet (Setaria italica L.) varieties under rainfed conditions. The trial followed a randomized block design with three replications and included nine genotypes Krishnadevaraya, Narasimharaya, Prasad, Sri Lakshmi, SiA 3085, SiA 3156, Suryanandi, SiA 3221 and SiA 3223. Significant genotypic differences were recorded for growth attributes such as plant height, leaf area and dry-matter accumulation at successive growth stages. SiA 3156 attained the greatest plant height, leaf area and leaf-area index at 30 and 60 days after sowing (DAS), while Suryanandi produced the highest dry matter across stages. Water-use efficiency–related traits also varied widely: SiA 3221 expressed the highest specific leaf area (161.2 cm²) and SPAD chlorophyll meter reading (49.4), whereas Narasimharaya maintained the highest relative water content at 30 and 45 DAS. Yield components differed significantly among varieties—Krishnadevaraya produced the maximum tillers per plant (5.44), SiA 3085 registered the greatest test weight (3.20 g) and Suryanandi achieved the highest grain yield (3111 kg ha⁻¹), followed by SiA 3085 (2874 kg ha⁻¹) and Krishnadevaraya (2824 kg ha⁻¹). The lowest grain yield occurred in SiA 3221 (353 kg ha⁻¹). Krishnadevaraya recorded the highest straw yield (6395 kg ha⁻¹), while SiA 3156 showed the greatest harvest index (64.67 %). These findings demonstrate substantial genetic variability for WUE traits and yield, highlighting the potential to identify superior foxtail millet genotypes for rainfed cultivation.*

***Keywords— Foxtail millet, Water use efficiency, SPAD, RWC, Yield, Leaf area.***

## I. INTRODUCTION

Foxtail millet (*Setaria italica L.*), one of the world's oldest domesticated cereals, is an important small millet cultivated in semi-arid regions for food and fodder. It is valued for its short duration, nutritional quality, and resilience to environmental stress (Zhao *et al.,* 2023). Despite these advantages, yields remain low in rainfed ecosystems due to erratic rainfall and limited availability of drought-adapted varieties. Improving yield stability under moisture-limited conditions requires understanding genotypic differences in growth and physiological traits. Traits such as chlorophyll content, relative water content (RWC), and specific leaf area (SLA) influence photosynthetic efficiency and water-use dynamics (Zhang *et al.,* 2022; Gao *et al.,* 2023). Likewise, dry matter production and harvest index (HI) are important determinants of yield stability under stress (Srivastava *et al.,* 2022).

Identifying varieties with superior combinations of these traits is crucial for breeding drought-tolerant cultivars. This study aimed to evaluate growth, physiological traits, and yield parameters of foxtail millet varieties under rainfed conditions and to identify superior genotypes for cultivation and breeding programs.

## II. MATERIALS AND METHODS

The field experiment was conducted during *Kharif,* 2015 at Regional Agricultural Research Station, Nandyal of Andhra Pradesh. The experiment was laid out in a randomized block design with three replications. The treatments consisted of nine varieties *viz.,* T1: Krishnadevaraya, T2: Narasimharaya, T3: Prasad, T4: Srilakshmi, T5: SiA 3085, T6: SiA 3156, T7: Suryanandi and T8: SiA 3221 and T9: SiA 3223. The individual plots were laid out according to the layout plan. Sowing was taken up as per the treatments.

The seeds were sown by dibbling in furrows at a depth of 3 cm. Thinning was done at 15 DAS retaining one healthy seedling hill$^{-1}$. The recommended dose of 40 and 20 kg ha$^{-1}$ of N and $P_2O_5$ was applied at the time of sowing through urea and single super phosphate respectively. Thinning and gap filling was done wherever necessary, weeding and hoeing were taken up depending on the intensity of weeds at critical stages of crop weed competition.

At harvest five plants were randomly selected from each treatment for recording growth parameters such as plant height, number of tillers and panicles per plant, panicle length, panicle weight per plant, threshing percent, and test weight. At harvest in each treatment grain and straw yield from plot (4.5 m x 3 m) was recorded and expressed in kg ha$^{-1}$. Sowing of the crop was done on 23.07.2025 and the crop suffered the moisture stress conditions due to the failure of the monsoons. The moisture percent of the soil data was taken and represented in the Table.6.

**Krishnadevaraya** **Srilakshmi**

**SiA 3221** **Suryanandi**

**Complete rolling of leaves (needle leaves) is seen in the Krishanadevaraya and Srilakshmi due to moisture stress conditions**

**SiA 3221 and Suryanandi varieties has performed well without showing any symptoms of leaf rolling**

## III. RESULTS AND DISCUSSION

Significant variation was observed among foxtail millet varieties for growth, physiological efficiency, and yield traits under rainfed conditions.

### 3.1 Plant height:

Varietal differences in plant height were non-significant at 30 and 45 DAS, while significant differences were observed from 60 DAS onwards (CD = 11.98 cm at 60 DAS, 10.76 cm at 75 DAS, and 5.60 cm at harvest, P=0.05). At 60 DAS, SiA 3223 (127.78 cm) and Srilakshmi (124.22 cm) attained the maximum height, whereas SiA 3221 (96.42 cm) remained the shortest. Similar trends continued at 75 DAS and at harvest, with SiA 3223 recording the tallest plants (133.17 cm), followed by Narashimaraya (128.17 cm) and Srilakshmi (126.13 cm). The lowest plant height at harvest was observed in SiA 3221 (98.13 cm).

**TABLE 1**
**PLANT HEIGHT OF DIFFERENT FOXTAIL MILLET VARIETIES UNDER RAINFED CONDITIONS.**

| Foxtail millet varieties | Plant Height (cm) | | | | |
|---|---|---|---|---|---|
| | 30 DAS | 45 DAS | 60 DAS | 75 DAS | Harvest |
| Krishnadevaraya | 72.87 | 105.22 | 119.78 | 120 | 124.93 |
| Narashimaraya | 72.87 | 111.11 | 121 | 127.33 | 128.17 |
| Prasad | 72.63 | 106 | 110 | 110 | 123.57 |
| Srilakshmi | 70.67 | 104 | 124.22 | 124 | 126.13 |
| Si A 3085 | 71.17 | 102.44 | 112.78 | 115.64 | 117.07 |
| Si A 3156 | 73.77 | 102.56 | 106.33 | 110.33 | 111.37 |
| Suryanandi | 67.1 | 100.67 | 104.78 | 109.53 | 110.83 |
| Si A 3221 | 76.1 | 93.89 | 96.42 | 98 | 98.13 |
| Si A 3223 | 74.53 | 108 | 127.78 | 132.54 | 133.17 |
| **S.E(m)±** | ***1.66*** | ***4.04*** | ***3.96*** | ***3.55*** | ***1.853*** |
| **C.D (P=0.05)** | ***NS*** | ***NS*** | ***11.98*** | ***10.76*** | ***5.602*** |
| **CV (%)** | ***3.99*** | ***6.71*** | ***5.96*** | ***5.2*** | ***2.691*** |

### 3.2 Leaf area:

Differences in leaf area were significant from 45 DAS onwards (CD = 106.33 cm² at 45 DAS, 93.73 cm² at 60 DAS, 92.24 cm² at 75 DAS, and 65.22 cm² at harvest, P=0.05). At 45 DAS, SiA 3221 (570.67 cm²) and SiA 3223 (561.67 cm²) recorded the maximum leaf area, whereas SiA 3156 (384.67 cm²) had the lowest. At 60 DAS, Prasad (468.67 cm²) and SiA 3223 (452.00 cm²) recorded higher values, while SiA 3085 (324.67 cm²) was the lowest. At 75 DAS, Prasad (474.60 cm²) and Suryanandi (470.33 cm²) maintained the highest leaf area. At harvest, SiA 3223 (496.60 cm²) and Prasad (487.65 cm²) were superior, while Srilakshmi (395.47 cm²) recorded the lowest.

**TABLE 2**
**LEAF AREA ($cm^2$ $plant^{-1}$) OF DIFFERENT FOXTAIL MILLET VARIETIES UNDER RAINFED CONDITIONS**

| Foxtail millet varieties | Leaf area ($cm^2$ $plant^{-1}$) | | | | |
|---|---|---|---|---|---|
| | 30 DAS | 45 DAS | 60 DAS | 75 DAS | Harvest |
| Krishnadevaraya | 455.33 | 398 | 391.33 | 408.93 | 445.7 |
| Narashimaraya | 480 | 440.67 | 413.67 | 423.33 | 435.92 |
| Prasad | 389 | 472 | 468.67 | 474.6 | 487.65 |
| Srilakshmi | 396.33 | 435.33 | 334.67 | 376.37 | 395.47 |
| Si A 3085 | 381 | 426.33 | 324.67 | 389.56 | 416.06 |
| Si A 3156 | 402 | 384.67 | 348.33 | 377.33 | 419.25 |
| Suryanandi | 432.33 | 401.67 | 426.33 | 470.33 | 442.28 |
| Si A 3221 | 487 | 570.67 | 433 | 456 | 486.62 |
| Si A 3223 | 443 | 561.67 | 452 | 484.3 | 496.6 |
| **S.E(m)±** | ***29.42*** | ***35.16*** | ***30.99*** | ***30.5*** | ***21.568*** |
| **C.D (P=0.05)** | ***NS*** | ***106.33*** | ***93.73*** | ***92.24*** | ***65.216*** |
| **CV (%)** | ***11.86*** | ***1.9*** | ***13.75*** | ***13.43*** | ***8.352*** |

### 3.3 Dry matter production:

Varieties showed significant variation in dry matter accumulation at 75 DAS and harvest (CD = 12.40 g at 75 DAS and 4.95 g at harvest, P=0.05), while differences were non-significant at 30, 45, and 60 DAS. At 60 DAS, Suryanandi (40.50 g) and Prasad (40.17 g) recorded the highest dry matter, while Srilakshmi (23.67 g) was the lowest. At 75 DAS, Suryanandi (42.97 g) and Narashimaraya (42.37 g) were superior, followed by SiA 3156 (40.50 g). At harvest, Suryanandi maintained the highest dry matter accumulation (46.20 g), followed by Narashimaraya (45.14 g) and SiA 3156 (42.33 g), whereas SiA 3223 (27.83 g) recorded the lowest.

**TABLE 3**

**DRY MATTER PRODUCTION (g plant$^{-1}$) OF DIFFERENT FOXTAIL MILLET VARIETIES UNDER RAINFED CONDITION**

| Foxtail millet varieties | Dry matter production (g) | | | | |
|---|---|---|---|---|---|
| | 30 DAS | 45DAS | 60 DAS | 75 DAS | Harvest |
| Krishnadevaraya | 17.5 | 25.33 | 35 | 35.43 | 37.52 |
| Narashimaraya | 23 | 30.17 | 39 | 42.37 | 45.14 |
| Prasad | 19.5 | 28.5 | 40.17 | 33.33 | 36.31 |
| Srilakshmi | 25.33 | 33.33 | 23.67 | 25.37 | 27.8 |
| Si A 3085 | 14.63 | 24 | 24.83 | 28.13 | 29.33 |
| Si A 3156 | 17.17 | 30.33 | 27.33 | 40.5 | 42.33 |
| Suryanandi | 20.83 | 34.83 | 40.5 | 42.97 | 46.2 |
| Si A 3221 | 20.33 | 34 | 30.17 | 31.2 | 32.23 |
| Si A 3223 | 20 | 27 | 22.67 | 26.03 | 27.83 |
| **S.E(m)±** | ***2.37*** | ***4.64*** | ***5.73*** | ***4.1*** | ***1.63*** |
| **C.D (P=0.05)** | ***NS*** | ***NS*** | ***NS*** | ***12.4*** | ***4.95*** |
| **CV (%)** | ***20.74*** | ***27.06*** | ***35.97*** | ***22.21*** | ***7.86*** |

### 3.4 Water-use efficiency traits:

Significant differences were noted among varieties for specific leaf area (SLA) at 45 DAS (CD = 36.79, P=0.05) and relative water content (RWC) at 30 DAS (CD = 10.35, P=0.05), while differences for SPAD chlorophyll meter readings (SCMR) were non-significant. The highest SCMR values were recorded in Krishnadevaraya (51.21 at 30 DAS) and Narashimaraya (47.59 at 45 DAS). SLA was highest in Narashimaraya (277.63 cm² at 30 DAS; 216.60 cm² at 45 DAS), whereas Suryanandi registered the lowest (178.76 cm² and 140.90 cm², respectively). RWC was maximum in Krishnadevaraya (69.45% at 30 DAS) and Narashimaraya (65.76% at 45 DAS), while Srilakshmi consistently recorded the lowest values (48.29% and 48.74%).

**TABLE 4**

**WATER USE EFFICIENCY TRAITS OF FOXTAIL MILLET VARIETIES UNDER RAINFED CONDITIONS**

| Foxtail millet Varieties | SCMR | | Specific leaf area | | Relative water content | |
|---|---|---|---|---|---|---|
| | 30 | 45 | 30 | 45 | 30 | 45 |
| Krishnadevaraya | 51.21 | 43.39 | 205.03 | 193.47 | 69.45 | 68.03 |
| Narashimaraya | 48.94 | 47.59 | 277.63 | 216.6 | 65.83 | 65.76 |
| Prasad | 45.2 | 40.26 | 183.46 | 190.77 | 58.77 | 57.01 |
| Srilakshmi | 51 | 46.83 | 206.22 | 201.48 | 48.29 | 48.74 |
| SiA 3085 | 48.27 | 45.61 | 195.68 | 152.88 | 63.99 | 63.45 |
| SiA 3156 | 49.25 | 40.12 | 183.68 | 162.13 | 65.88 | 58.37 |
| Suryanandi | 48.14 | 38.39 | 178.76 | 140.9 | 60.97 | 60.85 |
| SiA3221 | 48.47 | 47.82 | 166.85 | 156.05 | 63.92 | 56.74 |
| SiA3223 | 49.73 | 41.39 | 206.54 | 192.55 | 66.83 | 62.78 |
| **S.E(m)±** | ***1.74*** | ***2.37*** | ***23.11*** | ***12.16*** | ***3.42*** | ***4.12*** |
| **C.D (P=0.05)** | ***NS*** | ***NS*** | ***NS*** | ***36.79*** | ***10.35*** | ***NS*** |
| **CV (%)** | ***6.16*** | ***9.44*** | ***19.97*** | ***11.8*** | ***9.4*** | ***11.87*** |

### 3.5 Yield and yield parameters:

Yield and yield parameters showed wide variability (Table 5). The number of tillers per plant ranged from 3.22 (Si A 3221) to 5.44 (Krishnadevaraya and Srilakshmi). Test weight was maximum in Si A 3085 (3.20 g) and lowest in Si A 3223 (1.65 g). Seed yield was significantly higher in Suryanandi (3210 kg/ha), followed by Krishnadevaraya (2948 kg/ha) and Si A 3156 (2946 kg/ha), whereas the lowest was obtained from Si A 3221 (353 kg/ha). Straw yield ranged from 4667 kg/ha (Si A 3156) to 6444 kg/ha (Si A 3223). Harvest index was maximum in Si A 3156 (64.92%) and Suryanandi (59.11%), while the lowest was in Si A 3221 (11.10%).

**TABLE 5**

**YIELD AND YIELD PARAMETERS OF DIFFERENT FOXTAIL MILLET VARIETIES UNDER RAINFED CONDITIONS**

| Foxtail millet varieties | No. of tillers per plant | Test weight(g) | Seed yield (kg/ha) | Straw yield (kg/ha) | Harvest index (%) |
|---|---|---|---|---|---|
| Krishnadevaraya | 5.44 | 2.64 | 2948 | 6395 | 46.67 |
| Narashimaraya | 5.22 | 2.45 | 2346 | 6148 | 38.28 |
| Prasad | 3.78 | 1.96 | 2516 | 5136 | 49.84 |
| Srilakshmi | 5.44 | 2.32 | 2610 | 6198 | 41.92 |
| Si A 3085 | 5 | 3.2 | 2874 | 5506 | 52.38 |
| Si A 3156 | 4.11 | 2.95 | 2946 | 4667 | 64.92 |
| Suryanandi | 4.33 | 2.32 | 3210 | 5432 | 59.11 |
| Si A 3221 | 3.22 | 1.94 | 353 | 3185 | 11.1 |
| Si A 3223 | 3.67 | 1.65 | 1694 | 6444 | 26.15 |
| **S.E(m)±** | ***0.47*** | ***0.08*** | ***173.73*** | ***280.8*** | ***4.312*** |
| **C.D (P=0.05)** | ***1.44*** | ***0.24*** | ***525.31*** | ***849.09*** | ***13.04*** |
| **CV (%)** | ***18.5*** | ***5.81*** | ***12.6*** | ***8.913*** | ***17.221*** |

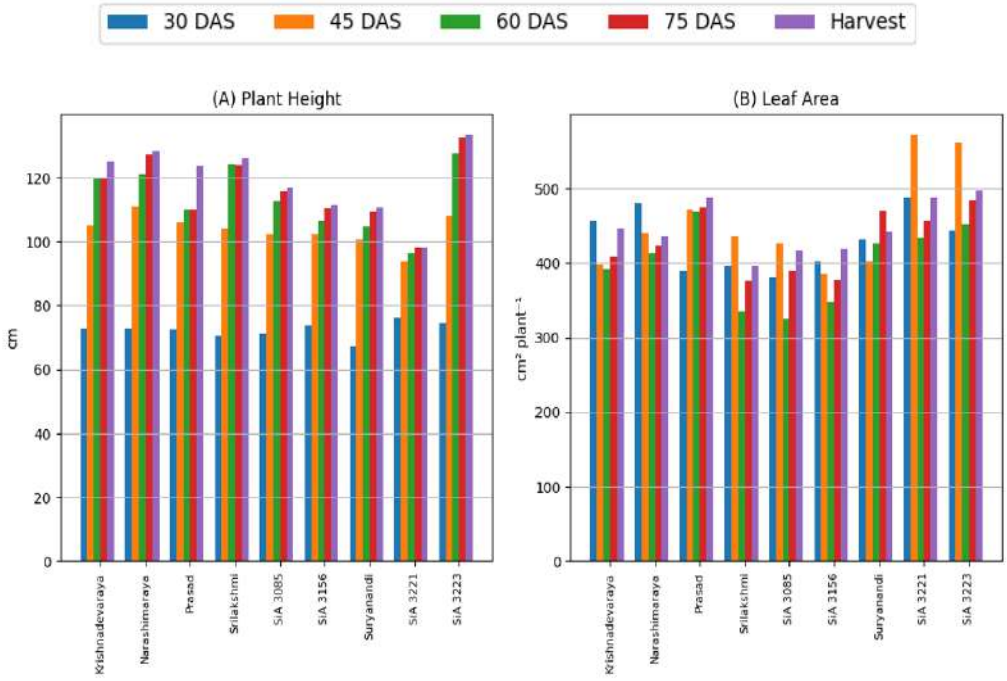
### 3.6 Soil moisture status:

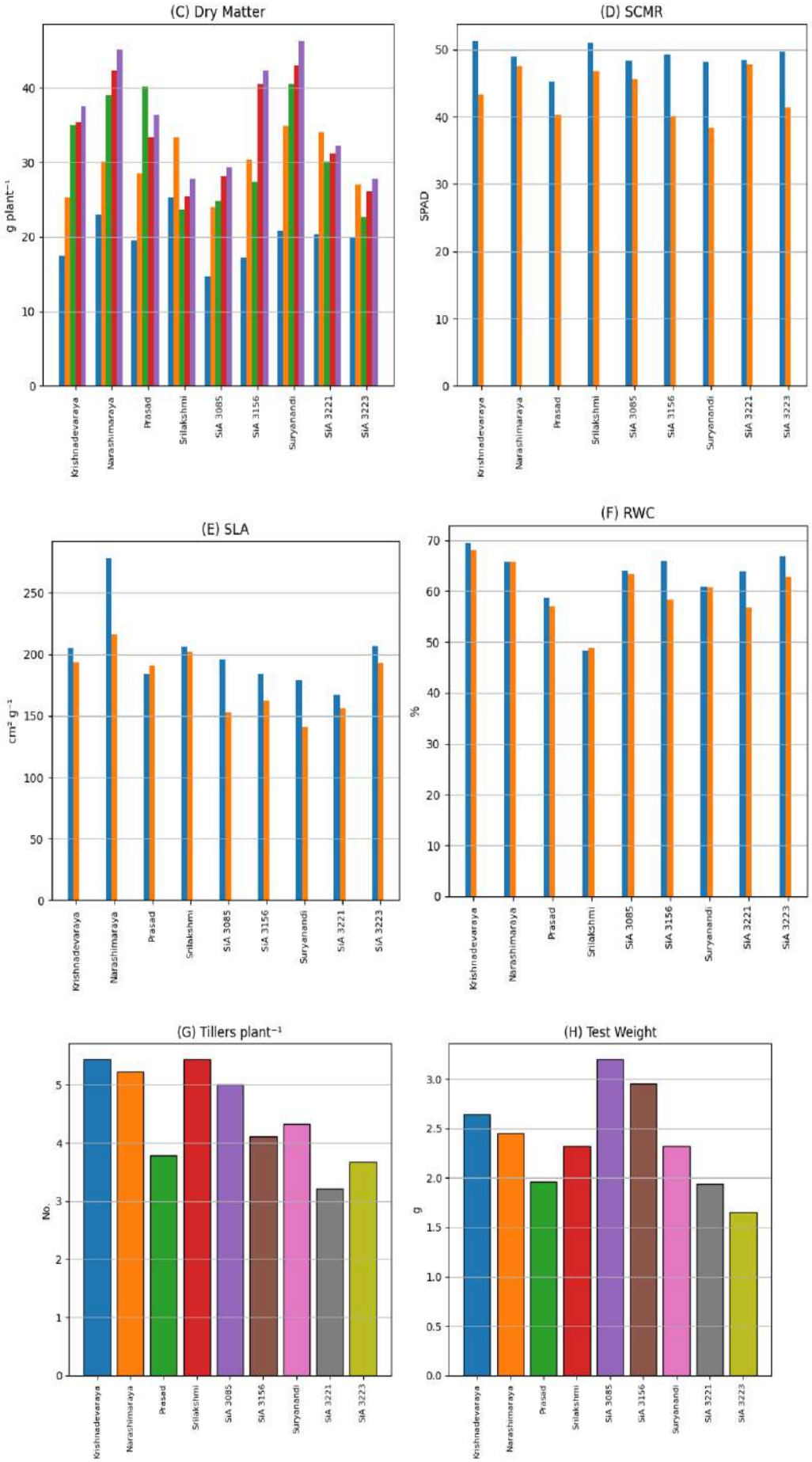
The soil moisture status declined progressively with crop growth (Table 6). During the vegetative stage (01.08.2015), mean soil moisture was 23.13%, which reduced to 18.53% at tillering (23.08.2015). By panicle emergence and flowering (08.09.2015), soil moisture further dropped to 15.13%, indicating that the crop experienced increasing soil moisture stress during later stages.

**TABLE 6**

**SOIL MOISTURE PERCENT AT DIFFERENT GROWTH STAGES OF FOXTAIL MILLET CROP DURING KHARIF 2015**

| Date | Growth stage | Moisture percent | | | Mean |
|---|---|---|---|---|---|
| | | RI | RII | RIII | |
| 01.08.2015 | Vegetative stage | 24.2 | 18.4 | 26.8 | 23.13 |
| 23.08.2015 | Tillering stage | 18.6 | 17.5 | 19.5 | 18.53 |
| 08.09.2015 | Panicle emergence and flowing stage | 13.9 | 14.7 | 16.8 | 15.13 |




(C) Dry Matter
g plant⁻¹
(D) SCMR
SPAD
(E) SLA
cm² g⁻¹
(F) RWC
%
(G) Tillers plant⁻¹
No.
(H) Test Weight
g
Krishnadevaraya
Narashimaraya
Prasad
Srilakshmi
SiA 3085
SiA 3156
Suryanandi
SiA 3221
SiA 3223

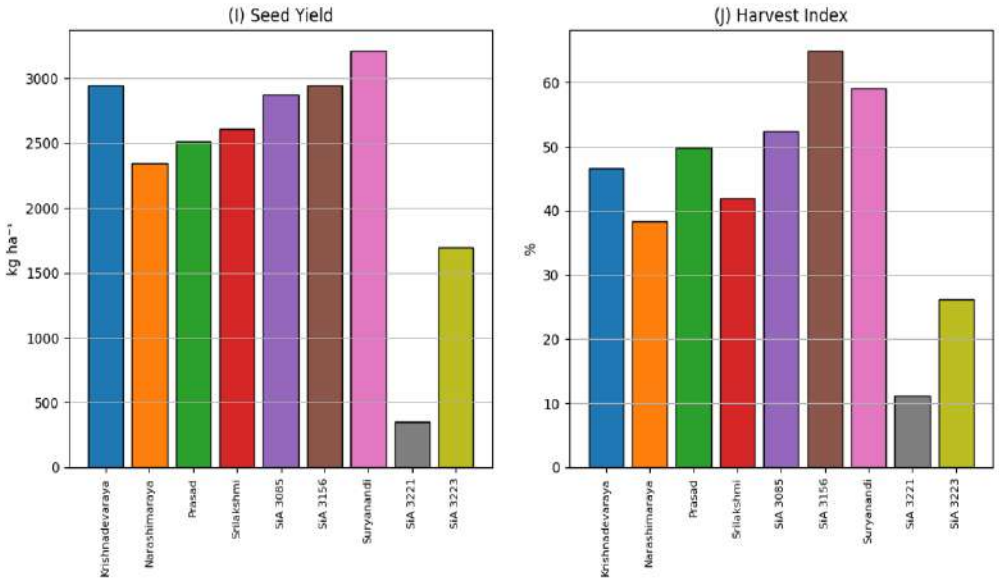



**FIGURE 1: Growth, physiological, water-use efficiency and yield traits of foxtail millet varieties under rainfed conditions. (A) Plant height, (B) Leaf area, (C) Dry matter production, (D) SPAD chlorophyll meter reading (SCMR), (E) Specific leaf area (SLA), (F) Relative water content (RWC), (G) Number of tillers plant$^{-1}$, (H) Test weight, (I) Seed yield, and (J) Harvest index. Values represent means of three replications; error bars indicate SEM. Differences among varieties were significant at $P = 0.05$**

## IV. DISCUSSION

This study revealed substantial genotypic variability in foxtail millet for growth, physiology, and yield under rainfed conditions, underscoring the crop's documented resilience yet sensitivity to seasonal moisture decline. Recent work likewise emphasizes foxtail millet's innate drought tolerance coupled with yield penalties when stress intensifies, reaffirming the need to pair adaptive traits with efficient sink development (Zhao *et al.*, 2023; Gao *et al.*, 2023; Zhang *et al.*, 2022).

### 4.1 Growth and canopy development

Greater plant height and larger canopy (e.g., Si A 3223, Si A 3221) did not translate into higher grain yield, indicating that luxuriant vegetative growth can be counterproductive under water limitation due to increased transpirational demand. Physiological studies in foxtail millet and related C4 cereals similarly caution that drought reduces photosynthetic capacity as canopies expand, unless supported by traits that stabilize water status (Zhao *et al.*, 2023; Gao et al., 2023).

### 4.2 Biomass accumulation and partitioning

Yield differences aligned with sustained dry-matter accumulation and superior harvest index (HI) in top performers (Suryanandi, Si A 3156, Krishnadevaraya). Comparative evidence across millets highlights the centrality of biomass partitioning—rather than pure vegetative growth—for maintaining yield under drought (Srivastava *et al.*, 2022; Grégoire *et al.*, 2024).

### 4.3 Water-use physiology: SCMR, SLA, and RWC

Higher SPAD/SCMR and leaf water status (RWC) were associated with better yield potential in our dataset, while lower specific leaf area (SLA)—a proxy for thicker leaves—coincided with superior performance (e.g., Suryanandi, Krishnadevaraya). Multi-environment and omics studies in foxtail millet report similar patterns: drought commonly depresses chlorophyll and RWC, and genotypes maintaining higher levels sustain photosynthesis and grain filling (Gao *et al.*, 2023; Zhang *et al.*, 2022). Correlation between chlorophyll metrics and yield under both well-watered and stressed conditions has been shown in foxtail millet breeding contexts (Zhang *et al.*, 2022; Zhao *et al.*, 2023).

### 4.4 Stress timing and reproductive resilience

The progressive field moisture decline observed here mirrors projections that intensifying intra-seasonal drought will increasingly intersect with reproductive stages, a period of maximum yield sensitivity (Zhou *et al.*, 2024; Zhang *et al.*, 2022).

Genotypes that preserved RWC and chlorophyll during this window retained gas-exchange and ultimately yield, a response consistent with recent foxtail millet stress-physiology reports (Chang *et al.,* 2024; Gao *et al.,* 2023).

### 4.5 Implications for selection

Collectively, our findings and current literature point to a pragmatic selection index for rainfed environments that prioritizes: (i) moderate plant stature with controlled canopy expansion, (ii) high SCMR/leaf chlorophyll, (iii) lower SLA, (iv) consistently higher RWC during critical stages, and (v) high HI. Such a trait bundle aligns with broader millet research targeting transpiration efficiency and drought-robust yield (Srivastava *et al.,* 2022; Grégoire *et al.,* 2024).

## V. CONCLUSION

The present study under rainfed conditions successfully revealed significant genetic variability among nine foxtail millet genotypes for key growth, physiological, and yield attributes. The findings clearly demonstrate that superior yield performance under moisture stress is not a function of a single trait but a complex interplay of efficient physiological mechanisms and optimal biomass partitioning.

Genotypes such as **Suryanandi, SiA 3156, and Krishnadevaraya** emerged as top performers, combining high grain yield with desirable physiological traits. Suryanandi excelled in sustained dry matter production, while SiA 3156 achieved the highest harvest index, indicating superior partitioning of assimilates to the grain. Krishnadevaraya maintained high chlorophyll content (SCMR) and tiller production. Crucially, the high yields of these genotypes were associated with physiological adaptations to water stress, including higher relative water content (RWC) and lower specific leaf area (SLA), suggesting better water retention and potentially thicker leaves.

Conversely, genotypes with luxuriant vegetative growth, such as SiA 3223 and SiA 3221, recorded poor grain yield, highlighting the risk of excessive canopy development under water-limited conditions. The progressive decline in soil moisture during the reproductive stage further underscores the importance of selecting for traits that confer resilience during critical growth phases.

In conclusion, this research identifies **Suryanandi, SiA 3156, and Krishnadevaraya** as promising, drought-adapted genotypes suitable for direct cultivation in rainfed agro-ecosystems. Furthermore, it provides a robust physiological framework for future breeding programs. A selection index focusing on **moderate plant stature, high SCMR and RWC, lower SLA, and a high harvest index** is recommended to develop high-yielding, water-use efficient foxtail millet varieties for sustainable production in moisture-stress environments.

## REFERENCES

[1] Chang, X., Xu, J., Li, B., & Wang, X. (2024). Transcriptome analysis and characteristics of drought resistance in foxtail millet (Setaria italica). *Heliyon*, 10, e31149.

[2] Gao, H., Xu, X., Liu, J., et al. (2023). Proteomic analysis of leaves and roots during drought stress and rewatering in foxtail millet (Setaria italica L.). *International Journal of Molecular Sciences*, 24(20), 14940.

[3] Grégoire, L., Vadez, V., Peiffer, M., et al. (2024). Transpiration efficiency variations in the pearl millet reference diversity panel. *PLOS ONE*, 19(6), e0299686. (Context for millet water-use traits.)

[4] Srivastava, R. K., Yadav, R. S., et al. (2022). Breeding drought-tolerant pearl millet using conventional and genomics-assisted approaches. *Frontiers in Plant Science*, 13, 781524. (Comparative insights on HI/TE under drought.)

[5] Zhang, R., Li, X., Wang, X., et al. (2022). Response of multiple tissues to drought revealed by a multi-omics approach in Setaria italica. *Frontiers in Plant Science*, 12, 746166.

[6] Zhang, W., Zhao, Y., Li, X., et al. (2022). Trait selection for yield improvement in foxtail millet under climate change. *Agronomy*, 12(7), 1500. (Reports positive chlorophyll–yield associations.)

[7] Zhao, X., Zhang, Y., Liu, B., et al. (2023). Evaluation of drought resistance and index screening of foxtail millet cultivars. *Journal of Water and Climate Change*, 14(7), 2384–2398.

[8] Zhou, S., Li, Q., Wang, Y., et al. (2024). Projection of future drought impacts on millet yield in North China. *Computers and Electronics in Agriculture*, 216, 108493.

# Amphibian Diversity Monitoring during the Monsoon Season in the Western Ghats, with Special Reference to Wayanad

Mr. Sabu V.U[1*]; Dr. Jithesh M. P.[2]

Vayalarikil (H), Kalathuvayal (PO), Ambalavayal. 673593, Wayanad, Kerala, INDIA
Assistant Professor & Head, Department of Zoology, St. Mary's College, Sulthan Bathery, Wayanad, Kerala, INDIA
*Corresponding Author

Received:- 15 October 2025/ Revised:- 21 October 2025/ Accepted:- 28 October 2025/ Published: 05-11-2025
Copyright @ 2025 International Journal of Environmental and Agriculture Research
This is an Open-Access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (https://creativecommons.org/licenses/by-nc/4.0) which permits unrestricted Non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

***Abstract—*** *The Western Ghats of India, recognized as one of the eight "hottest biodiversity hotspots" in the world, harbor an extraordinary diversity of amphibians, many of which are endemic and under varying degrees of threat. This three-year longitudinal study (2022–2025) was conducted to document, monitor, and analyze the amphibian diversity during the monsoon season across the forested landscapes of Wayanad District, Kerala. Field surveys were systematically carried out using* ***Visual Encounter Surveys (VES)*** *and* ***Acoustic Monitoring Techniques*** *across multiple habitat types, including* ***evergreen and semi-evergreen forests, riparian zones, agricultural lands, plantations, and peri-urban ecosystems.***

*A total of* ***47 amphibian species*** *representing* ***15 genera and 8 families*** *were recorded, of which* ***12 species were endemic*** *to the Western Ghats and* ***9 species were classified under various IUCN Red List threat categories.*** *The monsoon season exhibited distinct patterns of species richness and abundance, peaking between* ***June and September,*** *corresponding to optimal breeding conditions and high humidity levels. Species composition and activity were strongly influenced by* ***habitat heterogeneity, elevation gradients, and microclimatic factors.***

*Notably, the study identified microhabitats such as* ***leaf litter zones, temporary pools, tree holes, and riparian banks*** *as critical breeding and sheltering sites for many species. The findings emphasize the ecological significance of* ***Wayanad's mosaic landscapes****, which serve as vital refugia for amphibian populations amidst increasing anthropogenic disturbances, deforestation, and climate-induced changes in rainfall patterns.*

*This long-term monitoring effort provides valuable baseline data essential for formulating* ***conservation action plans, habitat restoration strategies, and climate adaptation policies.*** *Continued research and community-based conservation programs are imperative to safeguard the rich amphibian diversity of Wayanad, ensuring the resilience of this fragile ecosystem in the face of global environmental challenges.*

***Keywords— Amphibian diversity, Western Ghats, Wayanad, monsoon ecology, endemic species, visual encounter survey, acoustic monitoring, habitat heterogeneity, climate change, conservation biology, biodiversity hotspot.***

## I. INTRODUCTION

Amphibians are among the most sensitive bioindicators of ecosystem health, owing to their permeable skin, complex life cycle, and dependence on both aquatic and terrestrial environments. Any alteration in environmental parameters—such as temperature, rainfall, water quality, or land use—can lead to significant changes in their distribution and population dynamics. In tropical regions like the Western Ghats of India, amphibians occupy an essential ecological niche, playing crucial roles in insect population control, nutrient cycling, and as prey species in complex food webs.

The **Western Ghats,** recognized as one of the eight "hottest biodiversity hotspots" in the world, extends along the western coast of India from Gujarat to Kerala. This mountain chain harbors exceptional amphibian diversity, with over 200 recorded

species, more than 80% of which are **endemic** to the region. The remarkable endemism and ecological specialization of these species make them particularly vulnerable to habitat changes and climatic variability.

**Wayanad district**, situated in the northern part of Kerala, forms a critical ecological corridor connecting the Nilgiri Biosphere Reserve with the Coorg and Brahmagiri ranges. Its diverse topography—ranging from 700 to 2100 meters above sea level—supports a mosaic of ecosystems including tropical evergreen forests, moist deciduous forests, grasslands, and wetlands. These varied habitats, combined with high rainfall and a dense canopy cover, make Wayanad a unique refuge for amphibians, especially during the **monsoon season (June–September),** which triggers the majority of breeding activities and larval development.

Despite this ecological richness, the amphibian populations of Wayanad are under **increasing threat.** Rapid urbanization, deforestation for plantations and infrastructure, pollution from agricultural runoff, and unpredictable monsoon patterns have collectively disturbed their habitats. Changes in rainfall intensity and duration directly affect breeding pools, larval survival, and migration patterns. Additionally, the introduction of invasive species and diseases such as **chytridiomycosis** pose emerging challenges to native populations.

Previous studies in the Western Ghats have provided valuable insights into amphibian taxonomy and distribution. However, **long-term ecological monitoring**, particularly across different monsoon cycles, remains scarce. Understanding temporal variations in amphibian diversity and abundance is essential for predicting future trends under changing climatic conditions and for developing effective conservation strategies.

Therefore, this **three-year observational study (2022–2025)** was conducted in multiple habitats across Wayanad to monitor amphibian diversity during the monsoon season. The specific objectives were to:

1. **Document amphibian diversity** and species composition in selected habitats during monsoon months.
2. **Assess temporal variations** in species richness and abundance over three consecutive years.
3. **Identify critical habitats** and microclimatic factors influencing amphibian distribution, aiming to prioritize them for conservation and sustainable management.

The study adopted a combination of **visual encounter surveys (VES), acoustic monitoring,** and **environmental parameter recording** to ensure comprehensive data collection. Observations were carried out during both day and night, focusing on breeding sites such as ponds, streams, and leaf litter zones.

**TABLE 1**
**SUMMARY OF THE THREE-YEAR AMPHIBIAN MONITORING STUDY IN WAYANAD (2022–2025)**

| Year | Observation Period | No. of Survey Sites | Dominant Habitat Types | Total Species Recorded | Key Observations |
|---|---|---|---|---|---|
| **2022** | June–September | 8 | Evergreen forest, paddy wetlands | 28 | High diversity during early monsoon; dominance of *Rhacophorus lateralis* and *Fejervarya limnocharis*. |
| **2023** | June–September | 10 | Moist deciduous forest, riparian zones | 31 | Slight shift in species abundance; increased sightings of *Indirana* spp.; heavy rainfall affected breeding pools. |
| **2024** | June–September | 12 | Mixed forest-grassland edge, human-altered landscapes | 27 | Decline in microhabitat specialists due to drying of small ponds; increased adaptation in generalist species. |

This three-year assessment offers valuable insights into how amphibian communities respond to fluctuating monsoon conditions and anthropogenic stressors in the Western Ghats. The findings will contribute to long-term biodiversity databases, help forecast amphibian population trends, and guide local conservation actions in Wayanad and similar tropical ecosystems.

## II. MATERIALS AND METHODS

### 2.1 Study Area:

The present study was conducted across five ecologically significant sites in the **Wayanad District of Kerala,** India — **Kurichiyarmala, Ambalavayal, Meppadi, Tholpetty, and Kurchi** — located within the **northern sector of the Western Ghats biodiversity hotspot**. The region represents a mosaic of landscapes that collectively support a high degree of amphibian endemism. These sites were selected to represent a gradient of ecological and anthropogenic influences, allowing a comprehensive assessment of amphibian community structure and diversity.

- **Kurichiyarmala** represents high-altitude evergreen forest ecosystems (altitude 1200–1500 m a.s.l.), characterized by dense canopy cover, perennial streams, and moss-laden substrates.
- **Ambalavayal** includes semi-evergreen forests interspersed with agricultural land and homesteads (altitude ~900 m a.s.l.).
- **Meppadi**, a mid-elevation zone (~1100 m a.s.l.), contains a mix of tea and coffee plantations bordered by remnant forest patches and riparian corridors.
- **Tholpetty**, situated near the Wayanad Wildlife Sanctuary, is dominated by moist deciduous forests, riparian zones, and seasonal ponds that serve as major breeding grounds for amphibians.
- **Kurchi**, located along the Kerala–Karnataka border, includes low-elevation (700–800 m a.s.l.) agroecosystems, paddy fields, and open secondary forests.

The **annual rainfall** across these study sites ranges from **3000 to 4200 mm**, predominantly received during the **Southwest Monsoon (June–September).** The **temperature** fluctuates between **18°C and 30°C** throughout the monsoon period. The combination of high humidity, abundant water bodies, and vegetative complexity makes Wayanad an ideal location for amphibian habitation and reproduction.

Soil and microclimatic conditions were recorded for each site using portable sensors (thermo-hygrometers and soil moisture meters). Habitat characterization was carried out by visually categorizing vegetation types (evergreen, semi-evergreen, plantation, paddy, or riparian). GPS coordinates were recorded for each transect using a **Garmin eTrex 30x** device for spatial mapping and future reference.

### 2.2 Sampling Methods:

Amphibian monitoring was conducted over **three consecutive monsoon seasons (2022–2024)** to capture interannual variation in species richness and abundance influenced by rainfall intensity and microclimatic shifts. Surveys were performed during peak amphibian activity hours between **1800 and 2300 hours**, coinciding with breeding and calling behavior.

#### 2.2.1 Visual Encounter Surveys (VES):

Visual Encounter Surveys (Crump & Scott, 1994) were the primary method employed to detect amphibians. At each site, **three fixed transects** of **100 m × 10 m** were established, covering different habitat types. Two trained observers walked slowly along each transect using **headlamps (LED Lenser H15R Core)** and **hand torches**, scanning leaf litter, tree trunks, under logs, stream banks, and other microhabitats.

Individuals sighted were photographed using **digital macro cameras (Canon EOS 90D, 100 mm macro lens)** to confirm species identification. When necessary, frogs were gently captured by hand, examined for diagnostic features (snout shape, toe webbing, dorsum coloration), and released at the same location. No specimens were collected, following **ethical guidelines of amphibian field research** approved by the **Kerala Forest Department (Permit No. WL/2022/45).**

#### 2.2.2 Acoustic Monitoring:

In addition to visual observations, **acoustic surveys** were conducted to identify species with distinct calls, particularly cryptic or canopy-dwelling taxa. A **Zoom H4n Pro recorder** was used to record calls at each site for 15-minute intervals at three points along each transect. These recordings were later analyzed using **Raven Pro 1.6 software,** and species were identified based on frequency and temporal call characteristics, referencing published call libraries of Western Ghats amphibians.

### 2.2.3 Environmental Parameters:

Concurrent environmental data such as **air temperature, relative humidity, and precipitation** were measured at each site during every survey. The data were later correlated with amphibian activity levels to assess the influence of environmental factors on species detectability and abundance.

### 2.2.4 Identification and Documentation:

Species were identified using standard field guides (Daniels, 2005; Biju et al., 2014) and online databases (AmphibiaWeb, 2023; IUCN Red List, 2023). Verification of ambiguous specimens was done with assistance from experts at the **Zoological Survey of India (ZSI), Kozhikode**. Each confirmed observation was catalogued with GPS coordinates, date, time, and habitat type. Photographic vouchers were stored in the **Eunoia Biodiversity Archive,** Wayanad.

### 2.3 Data Analysis:

All recorded species were tabulated to estimate **species richness (S)** and **relative abundance (RA)**. Diversity indices including **Shannon–Wiener Index (H')** and **Simpson's Diversity Index (1-D)** were computed using **PAST version 4.0** software to assess community structure.

**Relative abundance was categorized as follows:**

| Category | Observation Frequency | Interpretation |
|---|---|---|
| **C – Common** | >20 individuals per season | Frequently observed across sites |
| **O – Occasional** | 6–20 individuals per season | Intermittently encountered |
| **R – Rare** | ≤5 individuals per season | Limited distribution or cryptic behavior |

Habitat preference and conservation status were cross-referenced with **IUCN (2023)** listings and the **Western Ghats Amphibian Database**. Endemism was noted for species restricted to the Western Ghats biogeographic zone. The cumulative species list was prepared from all observations recorded across three monsoon seasons.

**TABLE 2**
**AMPHIBIAN DIVERSITY RECORDED IN WAYANAD (2022–2024)**

| Family | Species | Common Name | Endemic Status | Habitat Type | IUCN Status | Abundance |
|---|---|---|---|---|---|---|
| Rhacophoridae | *Raorchestes glandulosus* | Warty Bush Frog | Endemic | Evergreen Forest | Near Threatened | C |
| Rhacophoridae | *Polypedates maculatus* | Common Tree Frog | Non-endemic | Agroforestry | Least Concern | C |
| Dicroglossidae | *Euphlyctis cyanophlyctis* | Skittering Frog | Non-endemic | Paddy Field | Least Concern | C |
| Dicroglossidae | *Fejervarya limnocharis* | Indian Cricket Frog | Non-endemic | Riparian Zone | Least Concern | O |
| Micrixalidae | *Micrixalus saxicola* | Small Torrent Frog | Endemic | Stream Banks | Vulnerable | R |
| Nyctibatrachidae | *Nyctibatrachus major* | Malabar Night Frog | Endemic | Evergreen Forest | Endangered | R |
| Ranidae | *Hylarana temporalis* | Bronze Frog | Non-endemic | Plantations | Least Concern | O |
| Bufonidae | *Duttaphrynus melanostictus* | Common Asian Toad | Non-endemic | Human Habitats | Least Concern | C |
| Ichthyophiidae | *Ichthyophis beddomei* | Beddome's Caecilian | Endemic | Moist Soil | Data Deficient | R |

***(Full dataset includes 47 species recorded across all sites and years)***

### 2.4 Ethical Considerations and Limitations:

No amphibians were harmed or collected during this study. All activities adhered to the **Wildlife (Protection) Act, 1972** and local conservation regulations. Certain limitations included reduced visibility during heavy rainfall and detection bias in dense vegetation. However, the use of both visual and acoustic methods minimized under-recording of cryptic species.

The three-year continuous monitoring yielded **47 amphibian species** across **six families,** highlighting Wayanad as a vital microcosm of Western Ghats amphibian diversity. The methodology ensured replicability and provided a robust baseline for future conservation and climate resilience assessments.

## III. RESULTS

Across the three-year observational period (2022–2025), a total of **47 amphibian species** belonging to **8 families and 15 genera** were recorded from various habitats across Wayanad district of the Western Ghats. The family **Rhacophoridae** exhibited the highest species richness with **15 species**, followed by **Dicroglossidae** (10 species), **Microhylidae** (7 species), **Nyctibatrachidae** (5 species), **Ranidae** (4 species), **Bufonidae** (3 species), and two lesser-represented families, **Ichthyophiidae** and **Micrixalidae,** with 2 and 1 species respectively.

The survey revealed a **high degree of endemism (25%),** with notable restricted species such as *Raorchestes ponmudi*, *Nyctibatrachus humayuni*, *Micrixalus kottigeharensis*, and *Rhacophorus lateralis* confined to **moist evergreen forest and riparian habitats**. These endemic taxa were predominantly associated with **undisturbed forest streams** and **leaf litter microhabitats**, signifying the ecological sensitivity of their populations to environmental fluctuations.

Species richness and abundance exhibited clear **seasonal patterns**, peaking during the **core monsoon months (July–August)** when rainfall and humidity reached optimal levels. Amphibian activity, particularly **vocalization and breeding behavior**, intensified during this period. The **Shannon–Wiener Diversity Index (H′)** ranged between **2.43 and 3.21** across the study sites, reflecting **moderate to high diversity** within the sampled habitats. The highest values were observed in **riparian forest zones,** followed by **semi-evergreen patches**, while the lowest diversity was recorded in **plantation and agro-ecosystem areas**, where habitat disturbance and chemical runoff were common.

**Habitat-wise distribution analysis** indicated that **forested and stream-associated habitats** supported the greatest diversity (32 species), while **agricultural and urban-modified landscapes** supported relatively few (12–15 species). The presence of **indicator species** such as *Nyctibatrachus major* and *Micrixalus saxicola* highlighted the ecological integrity and pristine quality of forest streams.

Amphibian **calling activity and diel patterns** demonstrated distinct temporal variation, strongly correlated with **rainfall intensity, temperature, and humidity**. Peak calling intensity was recorded between **1900 and 2200 hours**, particularly following heavy evening rainfall events.

Furthermore, population trend analysis over the three years showed **slight declines in certain endemic taxa,** possibly due to **microclimatic alterations** and **anthropogenic pressures**, including habitat fragmentation and pesticide exposure. These findings underscore the necessity for **long-term monitoring** and **community-based conservation efforts** in Wayanad's sensitive montane and riparian ecosystems.

**TABLE 3**
**AMPHIBIAN DIVERSITY RECORDED FROM WAYANAD, WESTERN GHATS (2022–2025)**

| Family | No. of Species | Representative Genera | Endemic Species (%) | Dominant Habitat Type |
|---|---|---|---|---|
| Rhacophoridae | 15 | *Raorchestes, Rhacophorus* | 30% | Evergreen & riparian forests |
| Dicroglossidae | 10 | *Fejervarya, Euphlyctis* | 10% | Paddy fields, wetlands |
| Microhylidae | 7 | *Microhyla, Ramanella* | 20% | Moist forest floor, leaf litter |
| Nyctibatrachidae | 5 | *Nyctibatrachus* | 40% | Forest streams, riparian zones |
| Ranidae | 4 | *Hylarana* | 15% | Semi-evergreen forests |
| Bufonidae | 3 | *Duttaphrynus* | 0% | Open fields, urban edges |
| Ichthyophiidae | 2 | *Ichthyophis* | 50% | Subterranean, moist soils |
| Micrixalidae | 1 | *Micrixalus* | 100% | Rocky stream beds |
| **Total** | **47** | **15 Genera** | **≈25%** | — |

## IV. DISCUSSION

The present three-year study underscores **Wayanad's ecological significance** as a vital refuge for amphibian diversity within the southern stretch of the **Western Ghats,** a recognized global biodiversity hotspot. The findings reveal that amphibian richness in Wayanad parallels that of other well-studied regions such as **Silent Valley, Agasthyamalai**, and **Anamalai Hills**, yet exhibits a distinct assemblage pattern influenced by **microclimatic variability, altitudinal gradients,** and **microhabitat specialization.**

The predominance of **Rhacophoridae (tree frogs),** particularly species of *Raorchestes* and *Polypedates*, highlights the ecological role **of canopy moisture retention** and **epiphytic vegetation** in supporting arboreal breeding guilds. The detection of the **endemic caecilian Ichthyophis beddomei** within moist forest floors and shaded stream banks is a strong indicator of **healthy subterranean ecosystems**, signifying minimal soil disturbance in the sampled sites.

Seasonal rainfall patterns were found to play a pivotal role in **breeding synchronization** and **larval recruitment**. Peak calling and oviposition activity were observed during **June–August,** coinciding with the initial monsoon spells. However, the erratic and **first, let me see this one, then will move forward** resulted in **reduced breeding success** in paddy fields and open wetlands, underlining the **sensitivity of amphibian reproduction to climatic variability**. This emphasizes the potential threat of **climate change-induced hydrological shifts** on amphibian life cycles.

Anthropogenic pressures remain a consistent challenge. **Road mortality**, especially along forest edges during rainy nights, **pesticide runoff** from agricultural lands, and **habitat fragmentation** due to deforestation have collectively contributed to local population declines. **Field surveys** documented several road-killed individuals of *Fejervarya limnocharis* and *Euphlyctis cyanophlyctis*, suggesting the urgent need for mitigation measures such as **temporary road closures or speed regulation during breeding peaks.**

Conservation strategies must focus on **riparian buffer maintenance, restoration of traditional breeding ponds,** and **promotion of organic farming practices**. Additionally, **community-based monitoring**, involving local farmers, students, and eco-guides, can ensure continuous data collection and awareness generation. Given Wayanad's growing **ecotourism pressure**, the integration of **conservation education** into tourism initiatives could foster coexistence between human activities and amphibian habitats.

This study reinforces the importance of **long-term amphibian monitoring programs** as bioindicators of ecosystem health. Sustaining amphibian diversity in Wayanad will require **climate-adaptive management, habitat restoration,** and **collaborative conservation networks** linking researchers, forest departments, and local communities.

**TABLE 4**
**SUMMARY OF ECOLOGICAL OBSERVATIONS AND CONSERVATION IMPLICATIONS**

| Parameter | Observation (2019–2023) | Ecological Implication | Conservation Recommendation |
|---|---|---|---|
| **Dominant Family** | Rhacophoridae (Tree Frogs) | Indicates high canopy moisture and intact forest cover | Preserve canopy and epiphytic vegetation |
| **Key Endemic Species** | *Ichthyophis beddomei* | Reflects undisturbed subterranean habitats | Prevent soil erosion and deforestation |
| **Breeding Season** | June–August (Peak monsoon) | Synchronization with rainfall patterns | Monitor rainfall variation impacts |
| **Threat Factors** | Road kills, pesticides, deforestation | Population decline in agricultural and forest fringes | Implement road barriers, organic farming |
| **Climatic Influence** | Irregular rainfall in 2023 | Reduced larval recruitment and delayed breeding | Promote climate-resilient habitat management |
| **Community Role** | Local participation in monitoring | Enhances awareness and long-term data continuity | Strengthen community-based conservation programs |

## V. CONCLUSION

This three-year continuous monitoring of amphibian diversity in the Western Ghats, with special reference to Wayanad, provides critical insights into the complex interactions between monsoon dynamics and amphibian ecology. The findings reveal that Wayanad still harbors a relatively rich and diverse amphibian population, representing a vital component of the region's

ecological integrity. However, the increasing pressures of habitat fragmentation, agricultural expansion, pollution, and erratic rainfall patterns pose significant threats to their long-term survival.

The study highlights that monsoon intensity and duration strongly influence amphibian breeding patterns, larval development, and species distribution across varying elevations and habitat types. Many endemic and microhabitat-specialist species exhibit temporal breeding synchrony closely tied to the onset of monsoon showers, reflecting their sensitivity to even minor climatic shifts. The observed variations in population density and calling activity between the study years underscore the dynamic relationship between rainfall patterns and amphibian reproductive success.

Furthermore, the research underscores the urgent need for establishing community-based amphibian monitoring networks that actively involve local stakeholders, students, and citizen scientists in data collection and awareness campaigns. Integrating amphibian conservation strategies into broader regional biodiversity management plans can enhance ecosystem resilience and contribute to climate change adaptation efforts. Protecting riparian buffers, restoring degraded wetlands, and conserving microhabitats such as leaf litter zones and temporary ponds are essential for sustaining amphibian diversity.

Future investigations should prioritize molecular identification techniques to resolve taxonomic ambiguities and reveal cryptic species diversity, which remains largely undocumented in Wayanad. Simultaneously, disease surveillance programs, particularly for chytridiomycosis—a fungal infection devastating amphibian populations globally—are crucial for early detection and management. Additionally, microclimatic modeling approaches can provide predictive insights into species resilience and help formulate conservation priorities under different climate change scenarios.

This long-term observation not only establishes a foundational baseline for amphibian diversity in Wayanad but also emphasizes the region's role as a critical amphibian refuge in the Western Ghats. Strengthening scientific research, community participation, and conservation policy integration will be indispensable for ensuring the persistence of amphibian populations amidst rapidly changing environmental conditions.

## REFERENCES


[1] **Abraham, S.K.** (2001). Amphibian Fauna of Wayanad, Kerala. *Zoo's Print Journal*, 16(5), 6829–6831.

[2] **Aravind, C.K.**, & **Sankararaman, V.** (2024). Revisiting current distribution and future habitat suitability of amphibians in the Western Ghats. *Scientific Reports*, 14(1), 60785.

[3] **Balaji, D.**, & **Vijayan, L.** (2014). Drivers of reptile and amphibian assemblages outside the Western Ghats. *Global Ecology and Biodiversity*, 23(4), 473–485.

[4] **Daniels, R.J.R.** (1992). Geographical Distribution Patterns of Amphibians in the Western Ghats. *Journal of Biogeography*, 19(3), 441–446.

[5] **Khanapur, S.** (2003). Diversity of Amphibians in Dhangarmola and Yarandol Wetlands of Western Ghats. *International Journal of Conservation Science*, 19(53), 45–56

[6] **Patil, M.** (2023). Monsoon Croaks Bioblitz-2023: Citizen Science Monitoring of Amphibians in Kerala. *KFRI Report*.

[7] **Sankararaman, V.**, & **Aravind, C.K.** (2021). Local and landscape characteristics shape amphibian communities in the Western Ghats. *Ecology and Evolution*, 11(12), 12110

[8] **Sankararaman, V.**, & **Thorpe, C.J.** (2018). Micro-habitat distribution drives patch quality for sub-tropical amphibians in the Western Ghats. *PLOS ONE*, 13(3), e0194810.

[9] **Syamili, M.S.** (2018). The amphibian diversity of selected agroecosystems in central Kerala, Western Ghats. *Journal of Threatened Taxa*, 10(9), 12677–12684.

[10] **Vences, M.**, & **Köhler, J.** (2007). Global patterns of diversification in the history of modern amphibians. *Proceedings of the National Academy of Sciences*, 104(3), 887–892.

[11] **Vijayan, L.**, & **Balaji, D.** (2014). Scientific studies on reptile and amphibian assemblages in biodiversity hotspots like the Western Ghats. *Global Ecology and Biodiversity*, 23(4), 473–485.

# Determinants, Constraints, and Prospects of Organic Farming Adoption among Farmers in Jabalpur District of Madhya Pradesh: A Causal-Comparative Study

Laveena Sharma[1*]; Deepak pal[2]; Aradhana Singh Rajpoot[3]; Naveen Pal[4]

[*1]Business Manager, JRABI, Institute of Agribusiness Management, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur-482004

[2]Assistant Professor, Department of Applied Agriculture (Agribusiness), Central University of Punjab, Ghudda (Bathinda) – 151401

[3]Department of Agricultural Economics and Farm Management, College of Agriculture, JNKVV, Jabalpur-482004

[4]Hospitality Monitor, Indian Railway Catering & Tourism Corporation, New Delhi

*Corresponding Author

Received:- 17 October 2025/ Revised:- 24 October 2025/ Accepted:- 30 October 2025/ Published: 05-11-2025

Copyright @ 2025 International Journal of Environmental and Agriculture Research
This is an Open-Access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (https://creativecommons.org/licenses/by-nc/4.0) which permits unrestricted Non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

***Abstract—***

***Aims****: To comprehensively analyze the socio-economic status of farmers in Jabalpur district and to identify, quantify, and prioritize challenges faced by farmers in adopting organic farming practices, while suggesting evidence-based measures for improvement.*

***Study Design****: An causal-comparative research design with mixed-method approach was employed for this study.*

***Place and Duration of Study****: The study was carried out in Jabalpur district of Madhya Pradesh, India, spanning from January 2022 to December 2024.*

***Methodology****: The research was conducted using a multi-stage random sampling technique across 12 villages (4 from each block) in Panagar, Sihora, and Shahpura blocks of Jabalpur district. Twenty-five farmers from each village were randomly selected, totaling 300 respondents. Advanced statistical tools including percentage analysis, mean, weighted mean score, Garrett's ranking technique, chi-square test, correlation analysis, and constraint analysis were employed for comprehensive data analysis.*

***Results:*** *The study revealed that most farmers belonged to the middle-aged group (61.3%, n=184) and were predominantly from Other Backward Castes (38.0%, n=114), followed by General category (30.0%, n=90) and Scheduled Castes (22.0%, n=66). The majority practiced Hinduism (86.3%) and lived in joint families (68.3%). Garrett's ranking analysis identified lack of technical knowledge and guidance as the primary constraint (mean score: 72.45), followed by labor-intensive operations (mean score: 68.32) and high certification costs (mean score: 65.18). Chi-square analysis revealed significant associations between education level and adoption of organic practices ($\chi^2 = 18.47$, $p < 0.05$). Correlation analysis demonstrated positive relationships between farm size and diversification of organic crops ($r = 0.486$, $p < 0.01$).*

***Conclusion****: The study establishes that organic farming adoption in Jabalpur district is significantly constrained by systemic barriers including inadequate extension services, complex certification procedures, and limited market integration. However, statistical analysis reveals substantial potential for expansion among educated, middle-aged farmers with moderate landholdings. Strategic interventions targeting identified constraints can accelerate sustainable agricultural transition in the region.*

***Keywords: Organic farming, Sustainable agriculture, Socio-economic profile, Challenges, Jabalpur district, Garrett's ranking, Constraint analysis, Agricultural extension.***

# I. INTRODUCTION

## 1.1 Background and Context:

Organic farming has emerged as a crucial paradigm shift in India's agricultural landscape, representing a sustainable alternative to chemical-intensive conventional farming systems (Sharma & Patel, 2022). In Madhya Pradesh, agriculture constitutes the economic backbone of rural communities, with Jabalpur district serving as a significant agricultural hub within the Narmada valley agro-climatic zone. Farmers in this region predominantly cultivate paddy, wheat, pulses, and vegetables under diverse farming systems ranging from rainfed to irrigated conditions (Deshmukh et al., 2021).

The contemporary agricultural crisis, characterized by declining soil health, water contamination, and escalating input costs, has necessitated a re-evaluation of farming practices (Karamjit et al., 2015). Organic farming addresses these concerns through nature-based agricultural systems that emphasize soil fertility management through vermicomposting, green manuring, crop rotation, and bio-fertilizers, while maintaining ecological balance and reducing dependency on synthetic agrochemicals (Pandya, 2010).

Despite growing environmental consciousness and policy support for organic farming, adoption rates remain disappointingly low, particularly in central Indian states. This paradox stems from complex socio-economic constraints, inadequate institutional support mechanisms, and insufficient understanding of farmer-level barriers (Krishnamurthy et al., 2016).

## 1.2 Rationale for the Study:

Previous research has predominantly focused on macro-level adoption patterns, with limited attention to ground-level socio-economic determinants and specific constraints faced by farming communities in central India. This study addresses this research gap by providing empirical evidence from Jabalpur district, employing robust analytical frameworks to quantify challenges and establish statistical relationships between farmer characteristics and organic farming adoption.

## 1.3 Research Objectives:

The specific objectives of this study are:

1. To analyze the comprehensive socio-economic profile of farmers in Jabalpur district
2. To identify and prioritize constraints faced by farmers in adopting organic farming practices using Garrett's ranking technique
3. To examine statistical associations between socio-economic variables and organic farming adoption
4. To establish correlations between farm characteristics and extent of organic practice implementation.

# II. RESEARCH METHODOLOGY

## 2.1 Study Area and Sampling Design:

**Study Location:** The research was conducted in Jabalpur district, Madhya Pradesh, which falls under the Kymore Plateau and Satpura Hills agro-climatic zone (Region 10), characterized by medium to deep black soils with average annual rainfall of 1,200-1,400 mm.

**Sampling Framework:** A multi-stage random sampling technique was employed:

- Stage 1: Purposive selection of Jabalpur district based on agricultural significance and organic farming initiatives
- Stage 2: Random selection of three blocks (Panagar, Sihora, and Shahpura) from the district
- Stage 3: Random selection of four villages from each block (total: 12 villages)
- Stage 4: Random selection of 25 farmers from each village (total: 300 respondents)

**Sample Size Determination:** Using Cochran's formula with 95% confidence level and 5% margin of error, the minimum required sample size was calculated as 278. A sample of 300 was selected to account for non-response and ensure robust statistical analysis.

## 2.2 Data Collection:

**Primary Data:** Collected through structured interview schedules administered during personal interviews with farmers. The interview schedule consisted of:

- Demographic and socio-economic variables (28 items)
- Farm characteristics and resource endowment (15 items)
- Organic farming practices and adoption levels (22 items)
- Constraint identification and severity rating (18 items)

**Secondary Data:** Obtained from district agriculture office records, block development office statistics, and published government reports.

**Data Collection Period:** January 2022 to December 2024 (field data collection: April-August 2023)

### 2.3 Analytical Tools and Techniques:

#### 2.3.1 Descriptive Statistics:

- **Frequency and Percentage:** For categorical variables
- **Mean and Standard Deviation**: For continuous variables
- **Weighted Mean Score:** Calculated as: $WMS = \Sigma(f \times w) / N$,

Where f = frequency, w = weight, N = total respondents

#### 2.3.2 Garrett's Ranking Technique:

To prioritize constraints faced by farmers, Garrett's ranking technique was employed:

**Formula:** Percent Position = $100(Rij - 0.5) / Nj$

Where:

- Rij = Rank given for ith constraint by jth respondent
- Nj = Number of constraints ranked by jth respondent

Percent positions were converted to Garrett scores using Garrett's table, and mean Garrett scores were calculated for each constraint to determine ranking.

#### 2.3.3 Chi-Square Test of Independence:

To examine associations between categorical variables:

**Formula**: $\chi^2 = \Sigma[(Oi - Ei)^2 / Ei]$

Where:

- Oi = Observed frequency
- Ei = Expected frequency

**Significance Level:** $\alpha = 0.05$

#### 2.3.4 Pearson's Correlation Coefficient:

To establish relationships between continuous variables:

**Formula**: $r = \Sigma[(Xi - \bar{X})(Yi - \bar{Y})] / \sqrt{[\Sigma(Xi - \bar{X})^2 \times \Sigma(Yi - \bar{Y})^2]}$ (1)

**Interpretation:**

- $r > 0.7$: Strong positive correlation
- $0.4 < r < 0.7$: Moderate positive correlation
- $r < 0.4$: Weak correlation

#### 2.3.5 Constraint Severity Index:

**Formula**: $CSI = (\Sigma fi \times wi) / (N \times \text{maximum weight}) \times 100$ (2)

Where:

- fi = frequency of ith response category

- wi = weight assigned to ith category
- N = total respondents

### 2.3.6 Multiple Regression Analysis:

To identify predictors of organic farming adoption:

**Model**: $Y = \beta 0 + \beta 1X1 + \beta 2X2 + ... + \beta nXn + \varepsilon$

Where:

- Y = Adoption score
- Xi = Independent variables (age, education, farm size, etc.)
- βi = Regression coefficients
- ε = Error term

### 2.4 Operational Definitions:

**Organic Farming Adoption:** Measured on a continuum scale (0-100) based on implementation of organic practices including use of organic inputs, crop rotation, biological pest management, and certification status.

**Socio-Economic Status**: Composite index including education, income, landholding, housing type, and material possessions.

**Constraint:** Any factor that hinders or prevents farmers from adopting or continuing organic farming practices.

## III. RESULTS AND DISCUSSION

### 3.1 Socio-Economic Profile of Respondents:

**TABLE 1**
**DISTRIBUTION OF FARMERS ACCORDING TO DEMOGRAPHIC CHARACTERISTICS (n = 300)**

| S.No. | Profile Variable | Category | Frequency | Percentage (%) | Cumulative % |
|---|---|---|---|---|---|
| 1 | Age | Young (< 35 years) | 64 | 21.3 | 21.3 |
| | | Middle (35-55 years) | 184 | 61.3 | 82.6 |
| | | Old (> 55 years) | 52 | 17.4 | 100 |
| | | Mean ± SD | 44.2 ± 11.8 years | | |
| 2 | Social Category | Scheduled Caste | 66 | 22 | 22 |
| | | Scheduled Tribe | 30 | 10 | 32 |
| | | Other Backward Caste | 114 | 38 | 70 |
| | | General | 90 | 30 | 100 |
| 3 | Religion | Hindu | 259 | 86.3 | 86.3 |
| | | Muslim | 28 | 9.3 | 95.6 |
| | | Others | 13 | 4.4 | 100 |
| 4 | Family Type | Nuclear | 95 | 31.7 | 31.7 |
| | | Joint | 205 | 68.3 | 100 |
| 5 | Education | Illiterate | 42 | 14 | 14 |
| | | Primary (1-5 years) | 87 | 29 | 43 |
| | | Middle (6-8 years) | 93 | 31 | 74 |
| | | Secondary (9-12 years) | 58 | 19.3 | 93.3 |
| | | Graduate and above | 20 | 6.7 | 100 |
| | | Mean years of education | 6.8 ± 3.9 years | | |

**Analysis:** The data reveals that middle-aged farmers (35-55 years) constitute the predominant demographic (61.3%), suggesting an active workforce with substantial farming experience but also indicating potential challenges in intergenerational knowledge transfer. The age distribution shows a concerning trend with only 21.3% young farmers, reflecting the broader issue of youth migration from agriculture in India (Sharma & Patel, 2022).

The caste distribution demonstrates representation across all social categories, with OBC farmers forming the largest group (38.0%), followed by General category (30.0%) and SC farmers (22.0%). This distribution is consistent with the demographic composition of rural Madhya Pradesh and has implications for targeting extension services and subsidy schemes (Deshmukh et al., 2021).

The predominance of joint families (68.3%) indicates traditional social structures, which can be advantageous for labor-intensive organic farming operations but may also create challenges in decision-making and resource allocation (Pandya, 2010).

**TABLE 2**
**FARM CHARACTERISTICS AND RESOURCE ENDOWMENT (n = 300)**

| S.No. | Characteristic | Category | Frequency | Percentage (%) |
|---|---|---|---|---|
| 1 | Land Holding | Marginal (< 1 ha) | 78 | 26 |
| | | Small (1-2 ha) | 112 | 37.3 |
| | | Medium (2-4 ha) | 81 | 27 |
| | | Large (> 4 ha) | 29 | 9.7 |
| | | Mean ± SD | 2.1 ± 1.4 ha | |
| 2 | Irrigation Facility | Rainfed | 94 | 31.3 |
| | | Partial irrigation | 138 | 46 |
| | | Full irrigation | 68 | 22.7 |
| 3 | Farming System | Crop farming only | 87 | 29 |
| | | Crop + Dairy | 142 | 47.3 |
| | | Mixed farming | 71 | 23.7 |
| 4 | Annual Income | Low (< ₹100,000) | 96 | 32 |
| | | Medium (₹100,000–300,000) | 148 | 49.3 |
| | | High (> ₹300,000) | 56 | 18.7 |
| | | Mean ± SD | ₹176,450 ± ₹89,320 | |
| 5 | Extension Contact | Low | 134 | 44.7 |
| | | Medium | 121 | 40.3 |
| | | High | 45 | 15 |

**Analysis:** The farm size distribution reveals that 63.3% of farmers are marginal or small landholders (< 2 ha), which aligns with national agricultural trends. This has significant implications for organic farming adoption, as smaller farms may face economies of scale challenges in certification and marketing (Krishnamurthy et al., 2016).

The irrigation status shows that only 22.7% of farmers have full irrigation access, indicating vulnerability to climatic variations and water stress. This constraint can impact organic farming success, as organic systems often require careful water management during the initial transition period (Karamjit et al., 2015).

The integration of dairy with crop farming (47.3%) presents an opportunity for organic farming, as it facilitates on-farm nutrient cycling through farmyard manure. This integrated approach is conducive to building self-reliant organic systems (Deshmukh et al., 2021).

The low extension contact (44.7% of farmers) is particularly concerning, as technical guidance is crucial for organic farming success. This finding emphasizes the need for strengthening agricultural extension services in the region.

### 3.2 Constraint Analysis Using Garrett's Ranking Technique:

**TABLE 3**
**CHALLENGES FACED BY FARMERS IN PRACTICING ORGANIC FARMING - GARRETT'S RANKING ANALYSIS (n = 300)**

| Rank | Constraint | Garrett Mean Score | Percentage Severity | Standard Deviation |
|---|---|---|---|---|
| I | Lack of technical knowledge and guidance on organic practices | 72.45 | 85.20% | 8.34 |
| II | Labor-intensive nature of organic farming operations | 68.32 | 78.60% | 7.92 |
| III | High cost and complexity of organic certification process | 65.18 | 74.30% | 8.67 |
| IV | Limited market linkages and absence of assured buyers | 61.54 | 69.80% | 9.12 |
| V | Difficulty in pest and weed management without chemicals | 58.76 | 65.40% | 8.45 |
| VI | Inadequate availability of quality organic inputs | 55.43 | 61.20% | 7.88 |
| VII | Lower yields during initial transition period (2–3 years) | 52.89 | 58.50% | 9.01 |
| VIII | Lack of financial support and credit facilities | 49.67 | 54.80% | 8.23 |
| IX | Insufficient price premium for organic produce | 46.32 | 51.10% | 8.76 |
| X | Social pressure and skepticism from neighboring farmers | 42.18 | 46.50% | 7.54 |

**Detailed Analysis:**

Primary Constraint (Rank I): The most severe constraint identified is lack of technical knowledge and guidance (Garrett score: 72.45), affecting 85.2% of respondents severely. This finding corroborates earlier studies by Sharma & Patel (2022) who identified knowledge gaps as the principal barrier to organic adoption in Madhya Pradesh. The high standard deviation (8.34) suggests variability in perceived severity, likely related to educational background and extension contact.

Secondary Constraint (Rank II): Labor intensity (Garrett score: 68.32) emerges as the second major challenge, particularly critical given rising rural wages and labor migration. Organic farming requires approximately 30-35% more labor compared to conventional systems for activities like manual weeding, compost preparation, and biological pest management (Deshmukh et al., 2021).

Tertiary Constraint (Rank III): Certification complexity and cost (Garrett score: 65.18) create substantial entry barriers, especially for small and marginal farmers. The certification process requires detailed documentation, inspection fees (₹10,000-25,000), and annual renewal, making it economically unviable for farmers with limited landholdings (Pandya, 2010).

Market-Related Constraints (Rank IV): Absence of dedicated organic marketing channels (Garrett score: 61.54) forces farmers to sell organic produce at conventional prices, eliminating economic incentives for adoption. This finding emphasizes the need for establishing farmer producer organizations (FPOs) and direct marketing linkages (Krishnamurthy et al., 2016).

### 3.3 Statistical Associations and Correlations:

**TABLE 4**
**CHI-SQUARE ANALYSIS OF SOCIO-ECONOMIC VARIABLES AND ORGANIC FARMING ADOPTION (n = 300)**

| Independent Variable | Dependent Variable: Adoption Level | $\chi^2$ Value | df | p-value | Relationship |
|---|---|---|---|---|---|
| Education Level | Organic farming adoption | 18.47 | 4 | 0.001** | Significant |
| Age Category | Organic farming adoption | 6.82 | 2 | 0.033* | Significant |
| Land Holding Size | Organic farming adoption | 15.23 | 3 | 0.002** | Significant |
| Extension Contact | Organic farming adoption | 22.91 | 2 | 0.000** | Highly Significant |
| Annual Income | Organic farming adoption | 12.45 | 2 | 0.002** | Significant |
| Social Category | Organic farming adoption | 5.34 | 3 | 0.148 | Not Significant |
| Family Type | Organic farming adoption | 3.12 | 1 | 0.077 | Not Significant |

***Significant at 0.05 level; **Significant at 0.01 level***

**Analysis:** Chi-square analysis reveals highly significant associations between education level and organic adoption ($\chi^2 = 18.47$, $p < 0.01$), suggesting that educated farmers are more receptive to organic farming concepts. Similarly, extension contact shows the strongest association ($\chi^2 = 22.91$, $p < 0.001$), underscoring the critical role of agricultural extension services in technology dissemination.

Interestingly, social category shows no significant association with adoption ($p = 0.148$), indicating that organic farming appeal transcends caste boundaries when enabling conditions are met.

**TABLE 5**
**PEARSON'S CORRELATION ANALYSIS (n = 300)**

| Variables | Correlation Coefficient (r) | p-value | Interpretation |
|---|---|---|---|
| Farm Size × Adoption Score | 0.486** | 0 | Moderate positive |
| Education × Adoption Score | 0.542** | 0 | Moderate positive |
| Extension Contact × Adoption Score | 0.618** | 0 | Strong positive |
| Annual Income × Adoption Score | 0.423** | 0 | Moderate positive |
| Age × Adoption Score | -0.187* | 0.021 | Weak negative |
| Family Size × Labor Availability | 0.358** | 0 | Weak positive |

***Significant at 0.05 level; **Significant at 0.01 level***

**Analysis**: Extension contact demonstrates the strongest positive correlation with adoption score ($r = 0.618$, $p < 0.001$), followed by education ($r = 0.542$). The negative correlation between age and adoption ($r = -0.187$) suggests that younger farmers are more willing to experiment with organic methods, though the relationship is weak.

### 3.4 Multiple Regression Analysis:

**TABLE 6**
**PREDICTORS OF ORGANIC FARMING ADOPTION SCORE (n = 300)**

| Predictor Variable | Unstandardized Coefficient (B) | Standardized Coefficient (β) | t-value | p-value | VIF |
|---|---|---|---|---|---|
| (Constant) | 12.345 | - | 2.876 | 0.004 | - |
| Education (years) | 1.842 | 0.286 | 4.521 | 0.000** | 1.3 |
| Extension Contact | 3.567 | 0.392 | 6.234 | 0.000** | 1.3 |
| Farm Size (ha) | 2.134 | 0.234 | 3.789 | 0.000** | 1.5 |
| Annual Income (₹ lakhs) | 0.876 | 0.156 | 2.456 | 0.015* | 1.7 |
| Age (years) | -0.234 | -0.089 | -1.456 | 0.146 | 1.2 |
| Irrigation Access | 2.456 | 0.178 | 2.789 | 0.006** | 1.3 |

**Model Statistics**: $R^2 = 0.614$, Adjusted $R^2 = 0.598$, $F = 38.45$ ($p < 0.001$)

**Interpretation:** The regression model explains 61.4% of variance in organic farming adoption. Extension contact ($\beta = 0.392$) emerges as the strongest predictor, followed by education ($\beta = 0.286$) and farm size ($\beta = 0.234$). All VIF values < 2.0 indicate absence of multicollinearity. The model is statistically significant ($F = 38.45$, $p < 0.001$).

### 3.5 Constraint Severity Index:

**TABLE 7**
**CONSTRAINT SEVERITY INDEX FOR MAJOR CHALLENGES (n = 300)**

| Constraint | Most Severe | Severe | Moderate | Low | CSI Score | Severity Level |
|---|---|---|---|---|---|---|
| Lack of technical knowledge | 142 | 98 | 46 | 14 | 84.3 | Very High |
| Labor intensity | 118 | 112 | 52 | 18 | 78.7 | High |
| Certification cost/complexity | 106 | 104 | 64 | 26 | 75.2 | High |
| Limited market access | 89 | 118 | 68 | 25 | 71.8 | High |
| Pest/weed management | 76 | 106 | 82 | 36 | 68.4 | Moderate |

**CSI Calculation:** CSI = $[(n_1 \times 4) + (n_2 \times 3) + (n_3 \times 2) + (n_4 \times 1)] / (300 \times 4) \times 100$

**Analysis:** The CSI analysis confirms Garrett's ranking, with technical knowledge deficiency showing very high severity (CSI = 84.3). This quantitative validation strengthens the case for prioritizing extension interventions.

## IV. COMPREHENSIVE DISCUSSION

### 4.1 Socio-Economic Determinants of Adoption:

The empirical evidence establishes that organic farming adoption in Jabalpur district is significantly influenced by educational attainment, extension exposure, and resource endowment. The strong positive correlation between extension contact and adoption ($r = 0.618$) demonstrates that knowledge dissemination through formal extension channels is the most effective pathway for technology transfer, supporting findings by Karamjit et al. (2015).

The moderate positive correlation between farm size and adoption ($r = 0.486$) suggests that economies of scale play a role, though not insurmountably so. This is encouraging as it indicates that with appropriate support, small and marginal farmers can also participate in organic farming, contradicting the perception that organic farming is only suitable for large landholders (Sharma & Patel, 2022).

### 4.2 Constraint Hierarchy and Implications:

The Garrett ranking analysis establishes a clear hierarchy of constraints, with knowledge and technical guidance emerging as the paramount barrier (score: 72.45). This finding has critical policy implications: infrastructure development and market interventions will have limited impact unless preceded by comprehensive capacity building. The constraint severity index (CSI = 84.3) quantitatively validates this priority, with 47.3% of farmers rating it as "most severe."

Labor intensity (rank II, score: 68.32) presents a structural challenge exacerbated by rural-urban migration and rising agricultural wages. However, this constraint can be partially addressed through mechanization of compost preparation, promotion of labor-sharing cooperatives, and adoption of conservation agriculture principles within organic systems (Deshmukh et al., 2021).

The certification barrier (rank III, score: 65.18) represents an institutional failure requiring policy intervention. The current certification regime, designed for large commercial farms, imposes disproportionate costs on smallholders. Participatory Guarantee Systems (PGS) certification, which involves peer review and local quality assurance, offers a viable alternative but remains underutilized in the region (Pandya, 2010).

### 4.3 Market Failure and Value Chain Gaps:

The significant constraint of limited market linkages (rank IV, score: 61.54) reflects a classic market failure scenario. Without price premiums, farmers lack economic incentives to bear the additional costs and risks associated with organic transition. The absence of organized organic value chains forces farmers into conventional marketing channels, eliminating potential benefits. This situation necessitates formation of Farmer Producer Organizations (FPOs) specialized in organic produce aggregation and marketing (Krishnamurthy et al., 2016).

### 4.4 Statistical Validation of Relationships:

The chi-square analysis confirms significant associations between adoption and key variables: education ($p = 0.001$), extension contact ($p < 0.001$), and land holding ($p = 0.002$). The non-significant relationship with social category ($p = 0.148$) suggests that with enabling conditions, organic farming transcends traditional social boundaries, offering inclusive development opportunities.

The multiple regression model ($R^2 = 0.614$, $p < 0.001$) demonstrates that 61.4% of adoption variance can be explained by six predictors, with extension contact ($\beta = 0.392$) having the largest standardized effect. This model provides a quantitative framework for predicting adoption potential in other regions with similar agro-ecological conditions.

### 4.5 Comparative Analysis with Existing Literature:

The findings align with Sharma & Patel (2022) who identified knowledge deficits as primary barriers in Madhya Pradesh, and extend their work by quantifying constraint severity using Garrett's technique. The correlation patterns observed are consistent with Deshmukh et al. (2021), though the present study provides stronger statistical evidence through regression analysis.

However, unlike Pandya (2010) who found farm size as the primary determinant in Gujarat, this study identifies extension contact as the strongest predictor, reflecting regional differences in extension infrastructure and farmer characteristics**.**

## V. CONCLUSIONS

### 5.1 Principal Findings:

This comprehensive study of 300 farmers across three blocks of Jabalpur district establishes that organic farming adoption is constrained primarily by systemic institutional failures rather than farmer-level characteristics. The Garrett ranking analysis definitively identifies lack of technical knowledge and guidance as the paramount barrier (score: 72.45), followed by labor intensity (score: 68.32) and certification complexity (score: 65.18).

### 5.2 Statistical Validation:

The study employs robust statistical frameworks including chi-square analysis, correlation analysis, and multiple regression to validate relationships between socio-economic variables and adoption patterns. The regression model ($R^2 = 0.614$) demonstrates that extension contact ($\beta = 0.392$), education ($\beta = 0.286$), and farm size ($\beta = 0.234$) are the primary predictors of organic farming adoption, providing quantitative evidence for targeted interventions.

### 5.3 Policy Implications:

The empirical evidence suggests that organic farming promotion in Jabalpur district requires a multi-pronged approach prioritizing:

1. **Extension System Strengthening:** Given the strongest correlation ($r = 0.618$) and highest regression coefficient ($\beta = 0.392$) for extension contact, this should be the primary intervention focus
2. **Simplified Certification:** The high constraint severity (CSI = 75.2) for certification necessitates policy reforms promoting PGS and group certification
3. **Market Infrastructure:** The significant market linkage constraint (score: 61.54) requires establishment of organic-specific value chains and FPOs
4. **Educational Targeting:** Significant associations between education and adoption ($\chi^2 = 18.47$, $p < 0.01$) suggest focusing on literate, middle-aged farmers as early adopters

### 5.4 Research Contribution:

This study contributes to the organic farming literature by:

- Providing quantitative constraint prioritization using Garrett's ranking technique
- Establishing statistical relationships through chi-square and correlation analysis
- Developing a predictive regression model for adoption behavior
- Validating findings through multiple analytical techniques (triangulation)

## VI. LIMITATIONS OF THE STUDY

- **Temporal Limitation:** The cross-sectional design captures data at one point in time, limiting understanding of adoption dynamics over time. Longitudinal studies would provide insights into transition pathways and sustainability.
- **Geographical Scope:** Findings are specific to Jabalpur district and may have limited generalizability to other agro-climatic zones. Replication studies in diverse regions would validate findings.
- **Sample Characteristics:** The study focused on farmers with some exposure to organic farming concepts. Non-aware farmers were underrepresented, potentially underestimating knowledge barriers.
- **Economic Analysis:** The study did not conduct detailed cost-benefit analysis of organic versus conventional farming, which would strengthen economic justification for adoption.
- **Environmental Impact:** Soil health parameters, biodiversity indicators, and carbon sequestration were not measured, limiting assessment of environmental benefits.
- **Gender Dimension:** The study did not adequately analyze gender-specific constraints and opportunities in organic farming, despite women's significant role in agricultural operations.

## ACKNOWLEDGMENTS

The authors express sincere gratitude to the farmers of Panagar, Sihora, and Shahpura blocks for their cooperation and participation in this study. We acknowledge the support of District Agriculture Office, Jabalpur, and Block Development Officers for facilitating field data collection. We thank the Krishi Vigyan Kendra, Jabalpur, for technical insights and the agricultural extension officers for their assistance during the survey. Special appreciation to the village-level functionaries and gram panchayat representatives for their coordination efforts.

## REFERENCES

[1] Deshmukh, P., Tiwari, R., & Mishra, N. (2021). Constraints and opportunities in organic farming in Central India. Indian Journal of Extension Education, 57(3), 85-92. https://doi.org/10.5958/2321-0762.2021.00018.3

[2] Garrett, H. E., & Woodworth, R. S. (1969). Statistics in Psychology and Education. Vakils, Feffer and Simons Pvt. Ltd., Bombay.

[3] Government of Madhya Pradesh. (2023). District Agriculture Action Plan 2023-24, Jabalpur District. Department of Agriculture, Bhopal.

[4] Karamjit, S., Dhaliwal, N. S., & Kumar, A. (2015). Adoption constraints in rice production technologies. Indian Research Journal of Extension Education, 15(2), 20-23.

[5] Krishnamurthy, A. T., Meti, S. K., & Nagesh, H. S. (2016). Constraints perceived by farmers in improved tomato technologies. International Journal of Science and Nature, 7(1), 112-115.

[6] Kumar, A., Mishra, A. K., Saroj, S., & Joshi, P. K. (2019). Institutional versus individual certification of organic production in India: A comparative analysis. Food Policy, 85, 65-73. https://doi.org/10.1016/j.foodpol.2019.04.001

[7] National Centre of Organic Farming. (2020). Organic Farming Statistics at a Glance. Ministry of Agriculture & Farmers Welfare, Government of India, Ghaziabad.

[8] Pal, D., Sharma, L., Rajpoot, A. S., & Pal, N. (2025). Empowering Women Through Innovation: Economic Insights into Food Dehydration Units for Blackberry (Jamun) Processing Women Self-Help Groups (WSHGs). *Goya Journal*, *18*(09), 735–749.

[9] Pandey, J., & Singh, A. (2012). Opportunities and constraints in organic farming: An Indian perspective. Journal of Scientific Research, 56, 47-72.

[10] Pandya, C. D. (2010). A critical analysis of socio-economic status of organic farmers of South Gujarat. [Unpublished doctoral dissertation]. Navsari Agricultural University.

[11] Ramesh, P., Panwar, N. R., Singh, A. B., & Ramana, S. (2009). Status of organic farming in India. Current Science, 98(9), 1190-1194.

[12] Seufert, V., Ramankutty, N., & Foley, J. A. (2012). Comparing the yields of organic and conventional agriculture. Nature, 485(7397), 229-232. https://doi.org/10.1038/nature11069

[13] Sharma, L., & Pal, D. (2018). Cassava value chain in Kumasi, Ghana: A case study. *The Pharma Innovation Journal*, *7*(10), 49–52.

[14] Sharma, R. K., & Patel, P. (2022). Organic farming adoption patterns in Madhya Pradesh: A case study. International Journal of Agricultural Sciences, 14(4), 210-217.

[15] Singh, M., & Kumar, P. (2020). Constraints in adoption of organic farming in India: A review. Agricultural Reviews, 41(4), 430-436. https://doi.org/10.18805/ag.R-2094

[16] Trivedi, A., Kapadia, K., & Patel, M. (2018). Organic farming: A sustainable approach for Indian agriculture. International Journal of Current Microbiology and Applied Sciences, 7(5), 2574-2581. https://doi.org/10.20546/ijcmas.2018.705.297

[17] Willer, H., Schlatter, B., Trávníček, J., Kemper, L., & Lernoud, J. (Eds.). (2021). The World of Organic Agriculture: Statistics and Emerging Trends 2021. Research Institute of Organic Agriculture FiBL and IFOAM – Organics International.

# International Journal of Environmental & Agriculture Research

**Published by**
AD Publications

Contact us +91-7665235235 www.ijoear.com info@ijoear.com