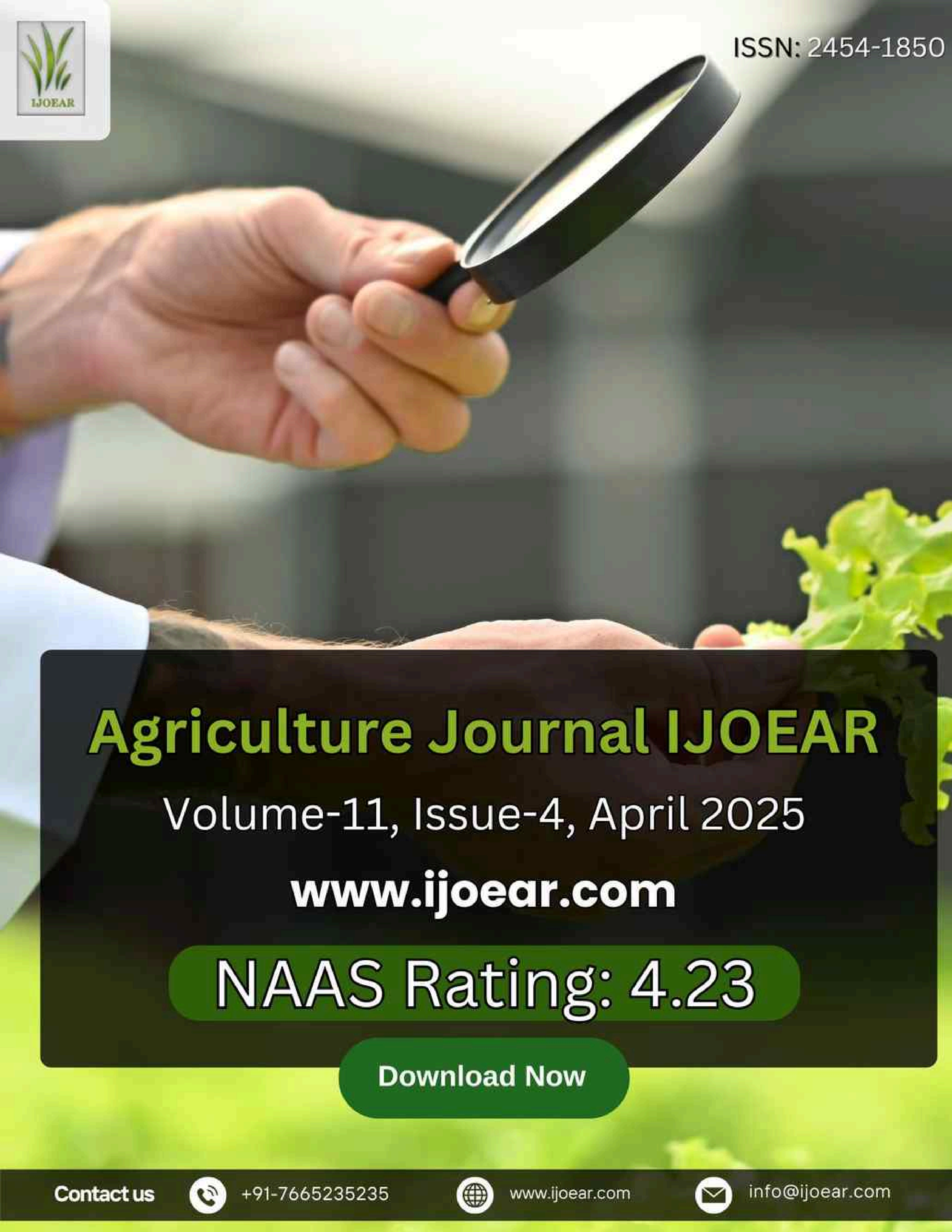

IJOEAR
ISSN: 2454-1850
Agriculture Journal IJOEAR
Volume-11, Issue-4, April 2025
www.ijoear.com
NAAS Rating: 4.23
Download Now
Contact us
+91-7665235235
www.ijoear.com
info@ijoear.com

Preface

We would like to present, with great pleasure, the inaugural volume-11, Issue-4, April 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. 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. 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-4, April 2025

Pharmaceutical and Agricultural Significance of *Trichoderma harzianum* Metabolites

N. Suresh

Post Graduate, Research Department of Botany, Vivekanandha College of Arts and Sciences for Women (Autonomous). Elayampalayam, Tiruchengode, Namakkal District, Tamil Nadu, South India. 637 205

Received:- 15 March 2025/ Revised:- 01 April 2025/ Accepted:- 10 April 2025/ Published: 30-04-2025

Abstract- *Currently, diseases are mainly managed by chemical pesticides. The use of these chemical pesticides causes environmental problems because they do not undergo biodegradation or degrade very slowly. Therefore, minimizing the use of pesticides has gained importance. To achieve this goal, biological control methods can be effectively combined with other disease control methods. Trichoderma sp. Soil-borne filamentous fungi are effective biocontrol agents against plant pathogens. The present investigation isolated antagonistic organisms and determined the antifungal activity of the antagonistic organisms in HPLC fractions of the mycelial extract. The antifungal activity of HPLC fractions of the mycelial extract were collected in separate vials; thereby, these HPLC fractions of the mycelial extract were analyzed by FT-IR, and many antibiotic compounds were identified. The FT-IR results were then confirmed by GC-MS.*

Keywords- GC-MS, Biocontrol, Trichoderma, FT-IR, HPLC.

I. INTRODUCTION

In recent years, Trichoderma spp. have been widely used in agriculture as biocontrol agents and inoculates to promote plant growth. They are involved in essential activities that ensure the stability and productivity of both agricultural and natural ecosystems. The potential of Trichoderma spp. to produce many volatile (e.g., pyrones, sesquiterpenes) and non-volatile secondary metabolites (e.g., peptaibols) has been reviewed by Reino et al. (2007). Volatile secondary metabolites have been shown to play a key role in the mycoparasitism of Trichoderma and its interaction with plants (Vinale et al., 2008). It is clear that the properties of Trichoderma to inhibit the growth of other fungi are likely due to the combined action of cell-wall degrading enzymes along with the ability of Trichoderma to produce different secondary metabolites. In some countries, there are several commercial formulations available to prevent diseases in crops as well as in economically important forest trees.

1.1 Pharmacological/Biological importance of different groups of secondary metabolites from *Trichoderma:*

Trichoderma spp, have also been reported to produce a plethora of secondary metabolites showing antimicrobial activity (Vinale et al., 2008). The chemical composition of these compounds depends on the strains, and they may be classified as volatile, water-soluble, or water-insoluble compounds (Ghisalberti & Sivasithamparam, 1991). The first demonstration of induced resistance was reported in 1997 (Bigirimana), who described the acquisition of resistance of bean plants towards *Botrytis cinerea* and *Colletotrichum lindemuthianum* after inoculation of the root with the strain T-39 of *Trichoderma harzianum* (Yedidia, Benhamou & Chet, 1999).

Species of Trichoderma have been demonstrated in vitro to act against fungal plant pathogens by producing diffusible volatile antibiotics. Vey, Hoagland & Butt (2001) reported that there are large varieties of volatile secondary metabolites produced by Trichoderma such as ethylene, hydrogen cyanide, aldehydes, and ketones which play an important role in controlling the plant pathogens (Bhagat Someshwar et al., 2014). Many species of Trichoderma are useful biocontrol organisms known to enhance crop yields and control soil-borne pathogens when added to soils. Our recent studies demonstrate that T. harzianum may be able to control the soil-borne pathogen. The aims of this study were to demonstrate that Trichoderma VOCs are a major factor in plant growth promotion and biocontrol. Finally, we characterized the volatile compounds identified by using gas chromatography–mass spectrometry (GC–MS) analysis. In addition, the identification of their biological activities such as anticancer and antiviral activities had been evaluated.

II. MATERIALS AND METHODS

2.1 Isolation and Identification of Antagonist organisms:

Fungal species were isolated from sugarcane rhizosphere soil samples by using potato dextrose agar (PDA) medium. Samples were inoculated over plates by multiple tube dilution technique (MTDT) and the plates were inoculated at 26˚C for 4 days. The fungal colonies were picked up and purified by streaking and incubated at 26˚C for 7-8 days. Conidia forming fungal bodies were selected and based on microscopic observation were identified to be *Trichoderma harzianum* Rifi**.,** *T. viride* Pers., *Aspergillus niger* Tiegh., *A. flavus* Links, *A. fumigates* Fresen., and *A. sulphureus.* Then the cultures were maintained on PDA slants.

Interaction between antagonistic fungi and pathogenic fungi were determined by the method of Dennis &Webster (1971a). The antagonism against used the pathogen (*Colletorichum falcatum*) was studied by dual culture technique. The isolated antagonistic organisms were cultured in nutrient broth, extracted using HPLC grade solvents and analyzed using HPLC. The HPLC analyses of mycelia extract showed few major and peaks. Antifungal activity of HPLC fractions of the mycelial extract were determined by collects the fractions in separate vials. The HPLC fractions of the mycelial extract were identified by FT-IR and the results of FT-IR were compared and confirmed by GC-MS

2.2 HPLC analysis:

From the mycelial extract, 5 µl was injected into the rp-18 octadeclysilyl silica (DDS) column (25 x 1 cm, i.d.) with LC-UV detector (P 3000, Analytical Technologies Limited) and monitored at 254 nm. The flow rate was adjusted to 1.5 µl min^{-1}. The fractionated samples were collected in separate vials.

2.3 Fourier Transform Infrared (FTIR) analysis:

The functional analysis of groups of phyto compounds were carried out by Fourier Transform Infrared Spectroscopy (FTIR). FTIR analysis was performed using Shimadzu 19WL FTIR spectrophotometer available in the common instrumentation centre, Government Arts College, Ariyalur. KBr pellets were made by accurately weighing 2 mg of dried and 300 mg of dried KBr and pressing the mixture under vacuum at 10 for 10 min. Measured wavelength range of 4000-400cm^{-1}. Data collection and processing was performed by GRAMS/386 version 3.02 software.

2.4 Gas chromatography – Mass Spectrum analysis of the culture filtrate:

2.4.1 Extraction of antifungal compounds:

The fungus which showed promising activity against the pathogen was cultured in liquid potato dextrose medium at 24°C in darkness for three weeks. After incubation, the culture was filtered twice through Whatman No.1 filter paper and Seitz filter (G.5). To 100 ml of culture filtrate, 10ml of ethyl acetate was added in a separation funnel (250ml), shaken well for 3 min. and the solvent and aqueous layer were separated. The acetonitrile layer of the culture filtrate was used for further analysis.

2.4.2 Gas chromatography – Mass Spectrometry (GC-MS):

Volatile components were identified by GC-MS using DB 5 - MS capillary standard non-polar column thermo GC - TRACE ULTRA ver: 5.0, THERMO MS DSQ II, with dimensions of 30 mts, ID: 0.25 mm, film: 0.25. The db 5 - ms capillary standard non-polar column detector was used. The carrier gas flow rate was 1 ml per min, split 10:1, and injected volumes were 2µl. The column temperature was maintained initially at 220°C for 2 min (hold), followed by increases up to 300°C at the rate of 5°/min-4 min (hold). The injector temperature was 255 °C, and this temperature was held constant for 36 min. Electron impact (EI) mass scan (m/z) was recorded in the 500 a MU range. Using computer searches on the NIST Ver.2.1 MS data library and comparing the spectrum obtained through GC-MS,the compounds present in the crude sample were identified. This analysis was carried out with the help of the lab technicians in SITRA LAB, Coimbatore.

III. RESULT AND DISCUSSION

3.1 Analysis of secondary metabolites through FT-IR and GC-MS:

3.1.1 FT-IR analysis of HPLC fractions:

The FT-IR analysis of the HPLC purified components of the culture filtrate of antagonistic soil fungi such as *Trichoderma* spp. (*T. harzianum, T. viride*) and *Aspergillus* spp. (*A. niger, A. flavus, A. fumigatus* and *A. sulphureus*) was carried out using Shimadzu FT-IR 1S with an inbuilt library. The analysis revealed the presence of humic acid, ethyl octoate, lineyl acetate, benzoic acid, pathalic acid, barbituric acid, formic acid, N-methyl-2-pyrolodine, formide, sulfosalicylic acid, adipic acid, tetroconazole, benslide, T-propanol-4, T-acetaldehyde-4, sulfomic acid, tetrahydrogen furan, artesunate, L-valine, Isoamylalcohol, kolin, bleomycin hydrochloride, polyvinylpyrolidene-4, T-carboxymethyl T-butanol, margarine, oleic acid, bismuth vanadate, tetraconazole, alginic acid, sodium thiosulfate, decalin, cyclohexon, molinate, olive oil, lauric acid. Carboxylic acid, ethyl vanillin-4, iminoctadine albesilate, ascorbic acid, 2-glucoside-4, oleamide, allyl hexanoate-4 and p-dimethylamino benzylidenerhodanine.

This study indicated that several compounds that have potential antimicrobial activity and plant growth promoting activity are present in *Trichoderma* spp. and *Aspergillus* spp. The plant growth promoting compounds include sulfosalicylic acid, N-methyl-2-pyrolodine, nicotinamide and humic acid. Some or all the components may be responsible for the antagonistic property of the *Trichoderma* spp. and *Aspergillus* spp. The results of the present study were in conformity with the earlier report by Prakash et al., Niveditha & Tejaswini (2010).

3.1.2 GC–MS Analysis:

We investigate the volatile metabolites excreted by the cultured only from *T. harzianum*, the potential antagonist organism isolated in the present study. The GC-MS data was de-convoluted using the NIST software, and the measured mass spectra were matched to entries in the compound library. When the extract of acetonitrile culture filtrate of *T. harzianum*was subjected to GC-MS analysis to find out the components produced by the fungus, it yielded five prominent peaks with retention time 15.06, 20.54, 25.37, 29.59, and 35.42 min. The peak area biological activity and chemical structure of phyto-compound that were identified is given in Table 1 and Fig. 1. Altogether, 54 compounds were identified, including indazole, furan, naphthanol, pyrazole, triazole, thiazole, quinoline, naphthalene, oxadiazole, thiophene, pyrimidine, pyridin, piperazine, Tetrazole-5-corboxylic acid, 2-phenyl, quinoline, naphthalene, benzimidazole and pyrazole, which were originally characterized, and identified as one of the key bioactive compounds of several species, e.g., *T. harzianum*. The results of the present study also support the work done by Dubey et al. (2011), where the presence of a wide range of secondary metabolites were obtained from the culture filtrate of *T. harzianum.* The results also revealed the presence of saponin, flavonoids, sterol, tannin and phenol, which are reported to have antimicrobial activity. The relatively high antimicrobial activity of *T. harzianum* isolated in the present study could be attributed to the presence of these compounds.

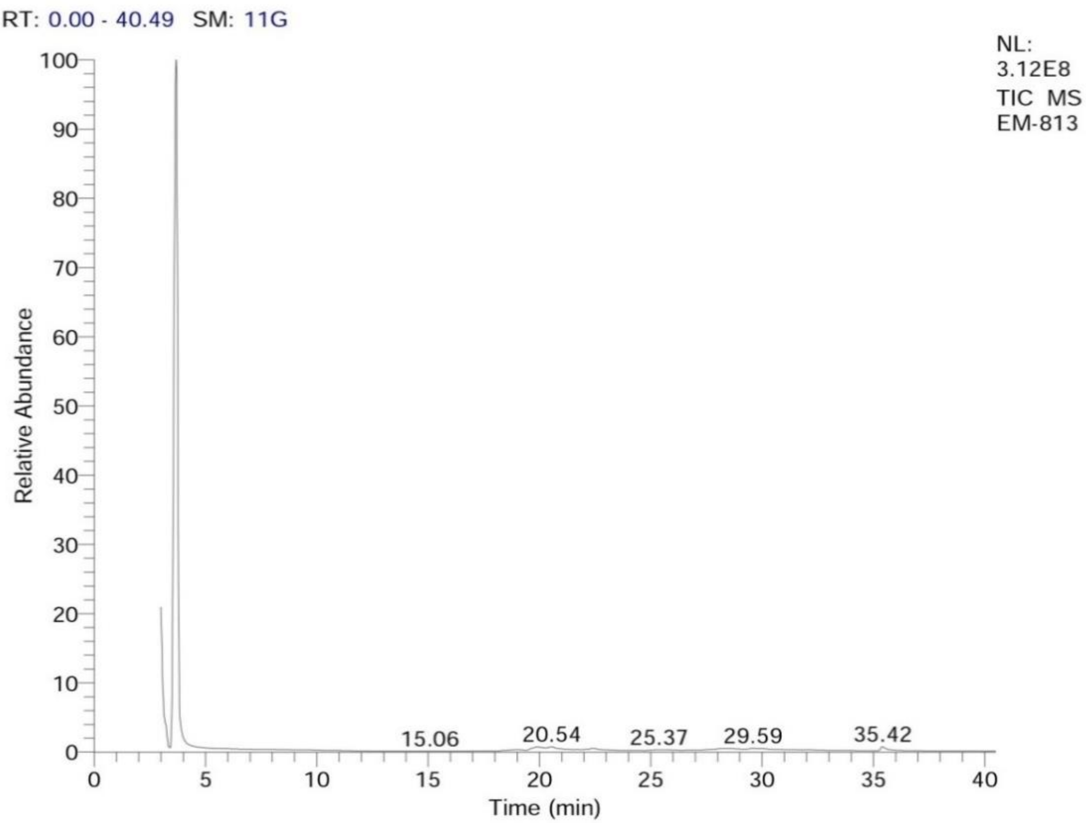


FIGURE 1: Characteristic features of antifungal compound isolated from *Trichoderma harzianum*by GC-MS

TABLE 1
NAME OF SECONDARY METABOLITES IDENTIFIED IN THE MYCELIAL EXTRACT OF *TRICHODERMA HARZIANUMUSING* GC-MS ALONG WITH THEIR ACTIVITY

Name of the Component	Activity
2-Methyl-4-vinyl-6,7-diphenyl-4H-pyrazolo[5,1-c]-1,4-oxazine	Analgesic, Antimicrobial activity, Antipyretic
1-Benzyl-3-methyl-5-(4nitrophenyl) pyrazole	Anti-inflammatory, Antimicrobial activity, Antioxidant
	Antioxidant,
2-Oxo-1-[N(1)-(aminocarbonyl)amino]-4,5-bis(methoxycarbonyl0-6-methyl-2,3 dihydro-1 H-pyrrolo[1,2-b]pyrazole	Anticancer agents, Insecticidal
-Ethyl-6-methyl-5-methylthiopyrazolo[1,5-a]pyrimidine	Antimicrobial activity
2-chloro-4-(2'-thiazolyl)-6-(2''-thienyl)pyrimidine	Anticancer activity, Antimicrobial activity
4-[1-(4-amino-1,2,5-oxadiazol-3-yl)-5-methyl-1h-1,2,3-triazol-4-yl]-1,3-thiazol-2-ylamine	Anti-inflammatory activity, Antimicrobial activity Antitubercular, Antiamoebic, Anthelmintic
1H-Indole,N-ethyl-5,6-dimethoxy-3-methyl-2-(4'methoxyphenyl)	Anti-inflammatory activity Antimicrobial activity
4,6-Dimethoxy-3-methylindolin-2-one	Nematicide, Pesticide, Antimicrobial activity
5-tert-Butyl-7-chloro-1H-indole	Antifungal activity
ethylmethyl-5-oxobeno[f][1,7]naphthyridine-2-carboxylate	Antifungal activity Pesticide degradation
2,2'-Diamino-3'-(methoxycarbonyl)-1,1'-binaphthy	Antifungal activity Antitumor
(R)-isopropyl 2-methoxy-1-naphthyl sulfoxide	Antifungal activity
8-dimethylamino-1-naphthalenecarboxylic acid	Antifungal activity Anti-inflammatory activity
1-methyl-1H-cyclopropa[b]naphthalene	Antibacterial, Pesticide degradation Anti-inflammatory
6,6-dimethoxy-7,8-dihydrocyclohept[fg]acenaphthen-5(6H)-one	Antifungal activity
methyl5-(1,4-naphthoquinon-2-yl)-2-furancarboxylate	Antifungal activity
CIS(3A,9A)-9-phenyl-3,3,3A-triodeuterio-3A,4 dihydronaphtho (2,3-C)furan-1(3H)-one	Antibacterial, Antifungal activity
2-(1-propenyl)naphthanol	Antifungal activity, Pesticide degradation
2-Trichloroacetyl-1,2,3,4 tetrachloroisoquinoline	Antibacterial activity, Anti-tubercular
2,4-Dichloro-3-hydroxy-1H-pyrido[1,2-a]quinolin-1-	Anticancer, Antiproliferative, Antifungal and Antibacterial activities
1à-ethyl-1,2,3,4,6,7,12,12Bá-octahydro-1,3-cycloindolo[2,3-A] quinolizin-3A-methanol	Antimicrobial activity,
	Pesticide
1-Ethyl-6-fluoro-7-[5-(4-methyl-1-piperazinyl)-2,3,4triazabicyclo [3.3.0]oct-2-en-4-yl]-4-oxo-1,4-dihydroquinoline-3-carboxylic acid	Antimicrobial activity,
N-(5,6-dihydrobenzo[h]quinazolin-4-yl)-DL-proline	Antimicrobial activity
	Anticonvulsant agents
1-[3-(dimethylamino)propyl]octahydro-4(1H)-quinolinone	Antimicrobial activity

Quinolin-4-one,1-(3-dimethylaminopropyl)-octahydro-	Antimicrobial activity
3-(2-Hydroxy-1-methyl-2,2-diphenylethyl)-1H-quinoxalin-2-one	Antimicrobial activity
methyl5-(1,4-naphthoquinon-2-yl)-2-furancarboxylate	Antimicrobial activity
2-Acetyl-4-[2-(methoxycarbonyl)ethyl]-3-[(methoxycarbonyl) methyl]pyrrole oxime	Antimicrobial activity,
1-Ethyl-5,6,8-trihydroxy-4-oxo-1,4-dihydro-3-quinolin carboxylic acid	Antimicrobial activity
5,6,8-Trimethoxy-7-methyl-4-phenyl-2(1H)-quinolinone	Antimicrobial activity
6,7-Dimethoxy-3,4-dihydroisoquinoline - N-Oxide	Antimicrobial activity
2-Chloro-3-methyl-5-methoxyquinoline	Antitubercular Activity
1-Hydroxymethyldibenzothiophene	Chemotherapeutic agents,
	Anti-atherosclerotic agents
Thiophene,2-[(2-fluoro-5-nitrophenylimino)methyl]-3-methyl-	Herbicides/ Pesticides, Anti-atherosclerotic agents
Ethyl2-amino-4-(4-fluorophenyl)-3-thiophenecarboxylate	Insecticide
1-ethyl-3-methyl-2-(2-methylpropylidene)imidazolidine	Antidiabetic Anti-inflammatory[
2-(2'-Furyl)benzimidazole	Anti-inflammatory, Antimicrobial, Antifungal, Antihyperglycemic,
Furan,2-methyl-5-(2-methyl-3-nitrophenyliminomethyl)-	Antimicrobial, Antiviral activity
3-(Ethoxycarbonyl)-2-phenyl-5-[3'-methyl-4'(methoxycarbonyl) buta-1',3'-dienyl] furan	Anti-inflammatory, Antimicrobial, Antifungal, Anticonvulsant activity
(E/Z)-2-(2-nitro-1-phenylethen-1-yl) furan	Antitumor
trans-2,3-Dihydro-5-hydroxy-3-phenylbenzofuran-2 carboxalde hydeN, N-Dimethylhydrazone	pharmacological activities
N,N-dinitroso-piperazine-D8	Antidepressant, Antipsychotic, Tuberculosis,Anthelmenitics
1-(7-Methoxy-benzo[1,3]dioxol-5-ylmethyl)-4-pyridin-3-ylmethyl -piperazine	Asantituberculosis, Anthelmenitics, Antianginals, Anti-Cancer, Analgesic, Antidepressant, Antpsychotic, Antidiabetic, Antihistamines, Hypolipidemic and Flavouring Agent
1,2,6-Trimethyl-4,4-tetramethylene-1,4-dihydropyridine-3,5-dicarbonitrile	anthelmenitics, antianginals, anti-cancer
2-(p-ethylbenzyl)pyridine	Antimicrobial, Biological actvity
2-Bromo-6-(methylthio)-4-(3-pyridyl)pyridine	Antiviral, Anticancer, Antimicrobial, Antidiabetic, Antitubercular
7-ethyl-3-methyl-2-nitro-4-oxo-4,7-dihydrothieno[2,3-b]pyridine-5-carboxylic acid	**Antioxidant** **Antimicrobial activity**
N-carbamoylimino-D5-pyridiniumbetaine	Antimicrobial activity
(5-ethyl-2-imino-4-methyl-6-oxo-3,6-dihydro-1(2h) pyrimidinyl) acetic acid	Antifungal activity
7-(cis-2'-Hydroxy-1'-cyclohexyl)-4-chloro-6-methylpyrrolo[2,3-d]pyrimidine	Anthelmenitics, antifungal activity
2-Acetylamino-4-trifluoromethyl-6,7,8,9,10,11,hexahydro 5,9;7,11-dimethano-5H-[9]annuleno[d]pyrimidine	Anti-inflammatory activity Antimicrobial activity
1-Butyl-6-hydroxy-4-methylhexahydropyrimidin-2-	Antioxidant and Cytotoxic activities

IV. CONCLUSION

The GC-MS analysis of the ethyl acetonitrile extract of *Trichoderma harzianum* has revealed the presence of a diverse range of bioactive volatile compounds, including Triazole, Imidazole, Thiazole, Pyrazole, Indole, Naphthalene, Furan derivatives, Pyrimidine, Thiophene, Quinoline, Pyridine, and Piperazine. These compounds exhibit significant potential for antimicrobial applications, indicating the pharmaceutical relevance of *T. harzianum*. Many of these metabolites can be isolated, purified, and chemically modified to enhance their efficacy against human pathogens. The findings highlight the role of *T. harzianum* as a promising source of natural antimicrobial agents, which could contribute to the development of novel drugs in combating infectious diseases.

In addition to their pharmaceutical applications, the bioactive compounds identified in this study also demonstrate considerable potential in agricultural and environmental sectors. The insecticidal, nematicidal, and pesticidal properties of these compounds provide an opportunity to develop sustainable and eco-friendly pest management strategies. Furthermore, their potential in pesticide degradation and herbicide formulation positions *T. harzianum* as a valuable tool in reducing chemical residues in the environment and promoting sustainable agriculture.

Overall, *T. harzianum* emerges as a versatile microbial resource with applications spanning pharmaceuticals, pest control, and environmental management. The ability to harness its bioactive metabolites paves the way for innovative solutions to address challenges in health, agriculture, and environmental sustainability. Future research should focus on the isolation and structural characterization of these compounds, along with in-depth studies on their mechanisms of action, to unlock their full potential and practical applicability.

V. ACKNOWLEDGEMENTS

The authors are thankful for the support of DST through FIST program (SR/FST/COLLEGE-/2022/1290:19.12.2022) and the PG Curie (DST/CURIE-PG/2024/28; 02.11.2024) for providing funds to equip the department of Vivekanandha College of Arts and Sciences for Women (Autonomous) to access high-end instruments used for the study.

REFERENCES

[1] Bigirimana, J., de Meyer, G., Poppe, J., Egad, Y. & Hofte, M. (1997) Induction of systemic resistance on bean (*Phaseolus vulgaris*) by *Trichoderma harzianum*. *Med. Fac. Landbouww. Univ. Gent*, 62, 1001–1007.

[2] Dennis, C & Webster, J. (1971a) Antagonistic properties of species groups of *Trichoderma*. I. Production of non-volatile antibiotics. *Transactions of the British Mycological Society*, 57, 25-39. DOI: 10.1016/S0007-1536(71)80077-3.

[3] Dubey, S.C., Tripathi, A., Bhavani, R., & Singh, B. (2011)Evaluation of seed dressing and soil application formulations of *Trichoderma* species for integrated management of dry root rot of chickpea. *Biocontrol Science and Technology*, 21, 93–100. DOI: 10.1080/09583157.2010.528557.

[4] Ghisalberti, E.L. & Sivasithamparam, K. (1991)Antifungal antibiotics produced by Trichoderma spp. Soil Biology & Biochemistry, 23, 1011–1020.

[5] Prakash, Karthik Raja R. Namasivayam N., Niveditha, N. & Tejaswini, K.VishnuV.(2010) Optimization of humic acid by *Trichoderma viridi* and its effect on sorghum plant. *Journal Biopesticides* 3, 155–157.

[6] Reino, J.L., Guerrero, R.F., Hernandez Galan, R.&Collado, I.G.(2007) Secondary metabolites from species of the biocontrol agent *Trichoderma*. *Phytochemistryn Reviews*, 7, 89–123. DOI: 10.1007/s11101-006-9032-2.

[7] Bhagat Someshwar, B., Ajanta Birah, Rakesh Kumar, Yadav, M.S., & Chattopadhyay, C. (2014) Plant disease management: Prospects of pesticides of plant origin. In: *Advances in Plant Bio-Pesticides* (edited by D. Singh).Springer India, pp. 119–129.

[8] Vey, A., Hoagland, R.E.&Butt, T.M.(2001)Toxic metabolites of fungal biocontrol agents. *Fungi as Biocontrol Agents*, 3, 11.

[9] Vinale, F., Sivasithamparam, K., Ghisalberti, E.L., Marra, R., Woo, S.L. Woo & Lorito, M. (2008). Trichoderma plant pathogen interactions. *Soil Biology and Biochemistry*, 40, 1–10. DOI: 10.1016/j.soilbio.2007.07.002.

[10] Yedidia, I., Benhamou, N & Chet, I. (1999. Induction of defense responses in cucumber plants (*Cucumis sativus* L.) by the biocontrol agent *Trichoderma harzianum*. *Applied and Environmental Microbiology*, 65, 1061–1070. DOI: 10.1128/AEM.65.3.1061-1070.1999, PubMed: 10049864.

Combining ability and heterosis for bud fly infestation and seed yield and it's attributes in linseed (*Linum usitatissimum* L.)

Dr. Rishi Pal

Associate Professor, (Agriculture), Meerut Institute of Technology Meerut (MIT), NH-58, Baral Partapur (U.P.)-India

Received:- 05 April 2025/ Revised:- 09 April 2025/ Accepted:- 18 April 2025/ Published: 30-04-2025

Abstract— *Four bud fly-resistant germplasm lines viz., EC-1424, GS-234, IC-15888, and JRF-5 were crossed with three testers (Neelum, Neela, and Shekhar) in a line × tester mating design to develop 21 F_1 and 21 F_2 crosses. The study was undertaken to estimate combining ability and heterosis in linseed (Linum usitatissimum L.) for bud fly infestation, seed yield, and related traits. The analysis of variance for general combining ability (GCA) and specific combining ability (SCA) was highly significant in both F_1 and F_2 generations.*

Based on per se performance and GCA effects, the best general combiners identified in both F_1 and F_2 generations were Neela for days to flowering and bud length; IC-15888 for sepal thickness, maturity duration, and bud fly infestation at the dough stage; Shekhar and Neela for grains per capsule; Neela for test weight; GS-234 and Neelum for oil content. However, no common general combiner was found for bud width, capsules per plant, and seed yield per plant across both generations. For capsules per plant, Shekhar was a good combiner only in the F_1 generation.

Heterosis over the superior parent for bud fly infestation at the dough stage ranged from –99.03% (EC-1424 × JRF-5) to –48.59% (Shekhar × Neelum) in the F_1 generation. Out of 21 crosses, 20 crosses exhibited significant negative economic heterosis for this trait. The top five promising crosses were EC-1424 × JRF-5, EC-1424 × Neela, GS-234 × IC-15888, GS-234 × JRF-5, and IC-15888 × Shekhar. Only one cross (EC-1424 × Shekhar) showed significant positive heterosis for bud fly infestation.

For seed yield per plant, heterosis over the economic parent ranged from 28.64% (JRF-5 × Neelum) to 51.90% (Shekhar × Neelum) in the F_1 generation. Among all crosses, six crosses exhibited significant positive heterosis. These cross combinations may serve as potential genetic resources in future linseed breeding programs aimed at improving yield and bud fly resistance.

Keywords— ***Combining ability, Heterosis Line × Tester, Linseed.***

I. INTRODUCTION

Linseed (*Linum usitatissimum* L.), commonly known as "Alsi", belongs to the genus *Linum* of the family Linaceae and has a chromosome number of 2n = 30. Globally, linseed is an important oilseed crop cultivated over an area of 27.29 lakh hectares, with a total production of 25.2 lakh tons and an average productivity of 923 kg/ha. In India, linseed is cultivated over 3.226 lakh hectares with a total production of 1.525 lakh tons, registering a comparatively low productivity of 473 kg/ha. India ranks third in terms of area under linseed cultivation, after Canada and China, but stands fifth in production following Canada, China, USA, and Ethiopia (Anonymous, 2013).

Continuous efforts towards yield improvement through hybridization and the selection of suitable parents are essential components of crop improvement programs. The line × tester mating design provides an effective method for precisely estimating the combining ability of parental lines and identifying superior parents and cross combinations. In this context, the present investigation was carried out to study the nature of combining ability and the extent of heterosis for yield, its contributing traits, and oil content in linseed

II. MATERIALS AND METHODS

The present experiment was conducted during *Rabi* 2020-21 at the Oilseed Research Farm, Kalyanpur, of Chandra Shekhar Azad University of Agriculture & Technology, Kanpur (U.P.). The experimental material comprised 49 genotypes, including 7 parents (4 lines and 3 testers), along with 21 F1 and 21 F2 progenies. The material was evaluated in a Randomized Complete Block Design (RCBD) with three replications.

Each genotype was sown in paired rows of 3 m length, maintaining a spacing of 30 cm between rows and 10 cm between plants. Observations were recorded on five randomly selected plants from each replication.

The data were recorded for eleven traits, namely: days to 5% and 90% flowering, flowering duration, number of bud fly maggots per 25 buds, bud fly infestation percentage at green bud stage and dough stage, bud shape (length and width), sepal thickness, flower colour, plant height, maturity duration, capsules per plant, seeds per capsule, test weight (g), seed yield per plant (g), and oil content (%).

The data were compiled and subjected to statistical analysis. Heterosis was estimated over the economic parent (Neelum), a commercial variety, while inbreeding depression (ID) in the F2 generation over F1 was estimated using the formulae given by Kempthorne (1957). Combining ability analysis was carried out following Griffing's (1956) Method 2, Model 1.

III. RESULT AND DISCUSSION

The mean sum of squares for all the characters are presented in **(Table-1)** Highly significant differences were recorded among all the treatments for all the 11 characters in both generations. The partitioning of treatments into parents and hybrids were also significant. Mean variances due to parents *viz* hybrid were also significant for majority of the characters. It indicated considerable variability with base material and material generated. Similar results were also reported by Singh *et al.* 1987, Thakur *et al.* 1987 and Khorgade *et al.* 1990.

Estimates of gca effects for 7 parents are presented in (**Table-2).** The highest positive and significant values of gca effects were considered desirable for the selection of good general combiners for all the characters except flowering duration, bud length, bud width, dough stage bud fly infestation and maturity period for which negative and significant values were desirable.

The gca and sca variances were highly significant both in F_1 and F_2 generations of the present study for all the characters except bud width in F_1 generation and oil content in F_2 which revealed that additive as well as non additive genetic effects were involved in the expression of these traits. However, additive effects were predominant for all the characters. Both gca and sca variances were found significant by Swarnkar *et al.* (2003) and Singh *et al.* (2004), Ratnaparkhi *et al.* (2005) and Singh *et al.* (2013).

The *per se* performance of parents was compared with their gca effects in F_1 and F_2 generations for all the characters under study. It was concluded that the parents having best *per se* performance were proved to be the best general combiners for almost all the characters. Chimurkar *et al.* (2001), Vishnu *et al. (*2005) and Kusalkar *et al.* (2003) also found almost similar results.

On the basis of *per se* performance and gca effects, the good general combiners common in both F_1 and F_2 generations were Neela for days to flowering, for bud length IC-15888, for sepal thickness IC-15888, for maturity duration Shekhar and Neela, for dough stage bud fly infestation % IC-15888, for Grain/capsules Neela, for test weight GS-234 and Neelum and for oil content Shekher. Not any general combiner was found common for character bud width, capsules/plant and yield/plant. For capsules/plant Shekhar only in F_1 generation. The consistency of combiners was stable. Stability for the important traits has been described as one of the important needs for breeding objectives.

The gca effects which included additive and additive x additive interactions (Griffing, 1956 and Sprague, 1966) represent fixable genetic variance (Gilbert, 1967). The additive parental effects measured by gca effects are of practical use. **(Table 3),** On the other hand, sca effects representing dominance and ecstatic components would not contribute much to the improvement of self pollinated crops except in cases where commercial exploitation of heterosis is feasible. Jinks and Jones (1958) further suggested that the superiority of many hybrids may not indicate their ability to produce transgressive segregants due to non-fixable genetic effects. Therefore, study of sca effects in segregating generations would be important.

TABLE 1
ANALYSIS VARIANCE FOR VARIOUS TRAITS OF LINSEED

Sources of variation	Generation	DF	Flowering duration (Days)	Bud length (mm)	Bud width (mm)	Sepal thickness (mm)	Maturity period (Days)	Dough stage bud fly infestation %	Capsules/ plant	Grains/ capsule	Yield/ plant (gm)	Test weight (1000) grains	Oil content %
Replicates	F_1	2	2.48	0.45	0.05	0.001	4.18	22.41	1000.33	0.107	5.40	0.05	0.54
	F_2	2	4.62	0.06	0.25	0.001	5.58	10.00	207.46	0.012	3.24	0.31	1.82
Treatments	F_1	27	25.14**	1.45**	0.31**	0.009**	129.28**	160.40**	4156.99**	2.791 **	19.82**	4.507 **	3.42**
	F_2	27	25.29**	1.34**	0.56**	0.008 **	132.69**	169.86**	3193.71**	2.594 **	19.63**	4.65**	4.33**
Parents	F_1	6	34.54**	3.12**	0.30*	0.02**	155.21**	437.10**	1084.89	2.714 **	10.11**	6.06 **	3.82*
Hybrids	F_1	20	22.40**	1.02**	0.31**	0.01**	126.93**	66.13**	2862.85**	2.938 **	14.54**	4.04 **	3.45**
	F_2	20	21.15**	0.87**	0.60**	0.01 **	132.36**	85.39**	1625.80**	2.354 **	9.93**	4.41**	4.69**
Parent Vs Hybrids	F_1	1	23.53*	0.05	0.53*	0.004*	20.57*	380.17**	48472.32**	0.321	183.8**	4.52 **	0.37
	F_2	1	52.48**	0.01	1.40*	0.001	4.06	250.56**	47204.77**	6.671 **	270.76**	0.80*	0.004
Error	F_1	54	5.39	0.40	0.10	0.001	4.03	9.23	643.36	0.416	2.01	0.13	1.41
	F_2	54	6.35	0.38	0.23	0.002	3.84	7.97	630.84	0.456	2.99	0.13	.1.44

NB: * and ** Significant at 5% and 1% level of significance, respectively

TABLE 2
GENERAL COMBINING ABILITY EFFECTS OF THE PARENTS FOR11 DIFFERENT TRAITS OF LINSEED

Source of variation	Generation	Flowering duration (Days)	Bud length (mm)	Bud width (mm)	Sepal thickness (mm)	Maturity period (Days)	Dough stage bud fly Infestation %	Capsules/ plant	Grains/ capsule	Yield/ plant (gm)	Test weight (1000) Grains	Oil content %
EC 1424	F_1	0.21	-0.15	-0.02	0.01	1.12**	-0.99	-7.61	-0.02	-0.48	-0.05	-0.51*
	F_2	0.28	-0.08	0.26**	-0.01	0.69	-2.18**	0.13	0.20	-0.22	-0.02	-0.52*
GS-234	F_1	0.02	0.26*	-0.08	-0.02**	-0.44	1.99**	-1.50	-0.28*	0.44	0.64**	-0.49*
	F_2	0.28	0.22	0.01	-0.00	-0.34	2.30**	2.099	-0.02	0.11	0.61**	-0.57*
IC-15888	F_1	-0.39	-0.36**	-0.01	0.04**	2.34**	-3.77**	2.46	-0.39**	-0.00	-0.32**	0.31
	F_2	-0.87	-0.28*	-0.12	0.04**	2.06**	-3.49 **	0.61	-0.43 **	-0.33	-0.20**	0.68**
JRF-5	F_1	0.95*	-0.15	-0.012	-0.01	2.38**	-0.80	3.68	0.24*	0.15	-0.40**	0.36
	F_2	1.31**	-0.29*	-0.01	-0.01	2.03**	-0.36	-6.87	0.02	-0.48	-0.68**	-0.16
Shekhar	F_1	-0.53	0.36**	0.06	0.00	-3.66**	0.42	9.76*	0.06	1.18**	0.40**	1.06**
	F_2	-0.50	0.18	-0.09	0.00	-4.09 **	-0.589	2.43	0.24	-0.43	-0.02	1.21**
Neelum	F_1	0.95*	0.02	0.04	-0.02 **	1.49**	3.98**	2.28	-0.05	-0.36	0.17**	-0.60**
	F_2	0.42	0.08	-0.06	-0.02*	2.58**	5.19**	3.58	-0.43 **	1.02**	0.37**	-0.59**
Neela	F_1	-1.20**	0.02	0.03	0.00	-3.22**	-0.82	-9.06	0.43**	-0.93 **	-0.44**	-0.14
	F_2	-0.91*	0.16	0.01	-0.01	-2.94 **	-0.87	-1.98	0.42**	0.34	-0.06	-0.05
CD 5%	F_1	1.01	0.28	0.14	0.01	0.89	1.32	11.06	0.28	0.62	0.15	0.52
CD 1%	F_1	1.53	0.42	0.21	0.02	1.33	2.01	16.76	0.43	0.94	0.23	0.79
CD 5%	F_2	1.10	0.27	0.21	0.02	0.86	1.23	10.95	0.30	0.75	0.16	0.52
CD 1%	F_2	1.66	0.41	0.31	0.03	1.30	1.86	16.59	0.45	1.14	0.24	0.79

NB: *, and ** Significant at 5% and 1% level of significance, respectively

TABLE 3
ESTIMATES OF SCA EFFECTS FOR VARIOUS CHARACTERS IN F1 AND F2 CROSSES IN LINSEED

S.N.	Hybrid combination	Generation	Flowering duration (Days)	Bud length (mm)	Bud width (mm)	Sepal thickness (mm)	Maturity period (Days)	Dough stage bud fly infestation%	Capsules/ plant	Grains/ capsule	Yield/ plant (gm)	Test weight (1000) grains	Oil content %
			sca effect	sca effect	sca effect	sca effect	sca effect	sca effect	sca effect	sca effect	sca effect	sca effect	sca effect
1	EC-1424×GS-234	F_1	-1.97	-1.10**	-0.2	0.07**	4.11**	-6.24**	-22.49	0.23	-1	-0.84**	-0.36
		F_2	-1.95	-0.42	0.06	0.06**	0.59	-6.47**	23.34	-0.44	2.65**	0.42*	-0.19
2	EC-1424× IC-15888	F_1	-1.64	-0.62	-0.2	0.05**	-1.11	-11.23**	69.36**	0.94*	2.74**	-0.14	-0.04
		F_2	-2.36	-1.10**	-0.59*	0.09**	-1.59	-9.70**	15.27	-1.25**	-1.07	-1.25**	1.43*
3	EC-1424× JRF-5	F_1	2.88*	-0.39	-0.35*	0.01	-1.11	-8.55**	28.66*	-0.95**	-0.93	-1.39**	-0.41
		F_2	-0.99	-0.74*	-0.37	0.02	-4.41**	-9.14**	33.75*	0.42	2.92**	0.94**	0.05
4	EC-1424× Shekhar	F_1	-2.12	0.74*	0.64**	-0.02	-4.15**	-3.80*	-14.9	0.58	-1.167	-0.23	0.44
		F_2	-1.84	0.52	-0.11	-0.01	-2.37*	-1.8	-27.44*	-1.36**	-1.06	-1.43**	-0.43
5	EC-1424× Neelum	F_1	-1.86	-0.13	0.14	-0.03	-2.33*	0.02	-10.38	-0.73*	-1.44	-1.41**	-0.02
		F_2	-2.14	0.18	0.18	0.02	2	-0.16	10.94	-0.32	2.70**	0.28	-0.14
6	EC-1424× Neela	F_1	-3.05*	-0.12	-0.46*	0	-2.89*	-8.10**	9.4	-0.32	0.37	-0.45*	0.05
		F_2	-1.47	0.23	-0.19	-0.05*	3.63**	-4.41**	7.9	0.79*	-0.95	-2.16**	-1.26
7	GS-234 × IC-15888	F_1	-0.49	0.06	0.08	0.06**	1.59	-5.46**	-13.64	0.12	-0.37	-1.57**	-0.46
		F_2	-1.36	-0.22	-0.07	0.02	2.59*	-3.57*	-5.18	0.23	0.61	-1.65**	-0.31
8	GS-234 × JRF-5	F_1	-1.31	0.04	-0.15	0.03	-6.41**	-0.8	2.32	0.90*	0.48	-0.11	-0.11
		F_2	-0.32	-0.55	-0.5	0.01	-0.89	-3.63*	2.97	0.57	0.26	-0.40*	-0.55
9	GS-234 × Shekhar	F_1	-1.31	-0.26	0.04	-0.04*	-4.44**	2.99	19.44	-2.07**	1.02	0.50*	1.6
		F_2	-3.18*	0.25	0.16	-0.04*	-4.85**	1.2	-8.55	-0.21	0.49	-0.37	0.53
10		F_1	-2.05	-0.48	-0.36*	-0.05**	0.7	0.39	4.95	0.79*	0.06	-0.12	-0.23
	GS-234 × Neelum	F_2	-1.14	-0.18	-0.25	-0.03	-0.48	5.66**	44.16**	0.49	2.78**	0.65**	-0.17

11	**GS-234 × Neela**	F_1	-1.23	0.26	0.28	0.01	-3.85**	-0.3	71.73**	0.53	1.48	-0.15	-0.42
		F_2	-0.14	0.28	0.05	0.01	-3.19**	-1.46	32.79*	0.6	1.04	1.06**	0.84
12	**IC-15888× JRF-5**	F_1	-2.31	-0.13	0.28	-0.02	-3.96**	-0.96	57.84**	-0.73*	3.66**	0.86**	-0.87
		F_2	-0.4	-0.42	-0.28	-0.01	-4.41**	-3.88*	27.57*	-0.58	0.09	-0.58**	-0.26
13	**IC-15888× Shekhar**	F_1	-1.64	0.06	-0.03	-0.02	-3.00**	-5.75**	-3.71	-0.03	0	-0.72**	0.85
		F_2	-2.58	0.89*	0.44	-0.01	-2.70*	-1.58	2.05	0.64	-1.07	-0.08	-0.19
14	**IC-15888× Neelum**	F_1	-1.38	0	0.38*	0.06**	0.15	0.93	19.81	-1.51**	1.25	0.76**	-0.29
		F_2	-1.88	-0.42	-0.42	-0.04	1.67	-3.32*	-3.58	1.34**	-1.5	-0.40*	-0.12
15	**IC-15888× Neela**	F_1	-2.90*	0.28	-0.44*	-0.01	-1.74	-1.29	-24.75	0.23	-1.70*	-0.74**	0.97
		F_2	-2.55	0.29	0.2	0.07**	-4.37**	-4.33**	38.38**	0.12	3.16**	1.19**	-0.05
16	**JRF-5× Shekhar**	F_1	1.21	0.65	-0.03	-0.05**	5.67**	3.62*	6.25	1.08**	-0.48	-1.24**	0.88
		F_2	2.12	0.49	-0.17	-0.04*	8.82**	6.60**	37.19**	0.97*	0.18	-0.76**	0.95
17	**JRF-5× Neelum**	F_1	2.14	-0.5	-0.61**	-0.07**	13.82**	0.05	51.10**	1.94**	2.27**	-0.44*	0.11
		F_2	2.82*	0.98**	0.57*	0.02	12.52**	9.25**	23.57	0.68	1.31	-0.21	-0.77
18	**JRF-5× Neela**	F_1	2.29	-0.72*	-0.04	0.04*	9.93**	2.61	-21.12	-0.32	1.03	-0.32	0.07
		F_2	-1.18	-0.41	-0.76**	-0.05*	6.12**	-0.76	-8.47	0.45	1.06	-0.70**	1.48*
19	**Shekhar× Neelum**	F_1	2.14	0.92*	0.25	-0.01	-5.89**	7.33**	19.21	-0.03	4.31**	1.37**	0.24
		F_2	2.97*	-0.52	-0.33	-0.01	-8.79**	1.27	4.05	-0.77*	2.83**	1.16**	0.93
20	**Shekhar× Neela**	F_1	1.95	0.93*	0.06	-0.03	-6.11**	1.99	9.66	1.38**	1.86*	1.83**	-0.69
		F_2	3.30*	0.95**	0.79**	-0.04*	-8.48**	3.84*	-14.66	0.34	2.75**	2.33**	-0.8
21	**Neelum× Neela**	F_1	6.21**	0.22	-0.25	-0.05**	5.05**	6.78**	32.51	-0.1	4.49**	1.74*	-0.55
		F_2	4.68**	-0.13	-0.01	-0.04*	5.89**	5.44**	51.38**	0.713	2.60**	0.78**	-1.05
Sij	**CD 5%**	F_1	2.51	0.68	0.35	0.03	2.17	3.28	27.42	0.7	1.53	0.38	3.76
	CD 1%	F_1	3.42	0.93	0.48	0.05	2.97	4.48	37.4	0.95	2.09	0.52	5.13
Sij	**CD 5%**	F_2	3.72	0.67	0.51	0.04	2.12	3.05	27.15	0.73	1.87	0.39	1.3
	CD 1%	F_2	4.05	0.91	0.7	0.06	2.89	4.16	37.03	0.1	2.55	0.53	1.77

NB: * and ** Significant at 5% and 1% level of significance, respectively

TABLE 4
ESTIMATES OF HETROSIS (%) OVER ECONOMIC PARENT OF YIELD COMPONENTS IN LINSEED 2020-21

S.No.	Characters'	Flowering duration (Days)	Bud length (mm)	Bud width (mm)	Sepal thickness (mm)	Maturity period (Days)	Dough stage bud fly infestation%	Capsules/ plant	Grains/ capsule	Yield/ plant (gm)	Test weight (1000) Grains	Oil content %
	Crosses F1	EH	EH	EH	EH	EH	EH	EH	EH	EH	EH	EH
1	EC-1424×GS-234	-38.09**	-21.72**	-11.5	48.27**	-3.18*	-79.17**	-3.84	0	-24.2	-37.89**	-0.14
2	EC-1424× IC-15888	-33.33**	-12.51*	-10.68	41.37**	-7.35**	-89.09**	102.9**	4.12	37.73*	-22.03**	4.2
3	EC-1424× JRF-5	-11.09	-17.97**	-16.98	41.37**	-2.94*	-99.03**	57.56**	-25.00**	-13.53	-42.32**	0.97
4	EC-1424× Shekhar	-28.57**	-2.84	10.13	13.79	-5.14**	72.67**	15.76	-12.5	-14.37	-31.10**	3.57
5	EC-1424× Neelum	-31.76**	-7.96	-5.2	6.89	-5.88**	-55.25 **	15.11	-20.87**	-14.27	-32.64**	-0.2
6	EC-1424× Neela	-36.52**	-12.51	-19.72**	31.03**	-5.14**	-84.54 **	28.3	-12.5	-4.86	-29.86**	-0.05
7	GS-234 × IC-15888	-38.09**	-4.89	-3.28	55.17**	-8.82**	-86.55 **	11.9	0	-1.26	-43.04**	4.35
8	GS-234 × JRF-5	-42.28**	-13.19*	-11.5	55.17**	-10.29**	-85.25 **	20.66	4.12	-4.75	-35.42**	1.49
9	GS-234 × Shekhar	-34.90**	-14.33*	-6.57	13.79	-8.82**	-67.44 **	37.95	-25.0**	2.64	-29.86**	8.26**
10	GS-234 × Neelum	-42.85**	-12.05*	-19.17*	6.89	-7.10**	-66.92 **	18.97	4.12	-4.54	-25.54**	-0.54
11	GS-234 × Neela	-38.09**	-8.3	0	37.93**	-9.31**	-76.60 **	77.50**	4.12	0.84	-33.05**	-.0.05
12	IC-15888× JRF-5	-42.85**	-11.26	1.09	41.37**	-8.82**	-82.45 **	91.97**	-20.87**	51.16**	-16.88**	4.43
13	IC-15888× Shekhar	-33.33**	-6.71	-7.39	20.68*	-8.08**	-87.29 **	33.77	-4.12	14.16	-33.82**	9.56**
14	IC-15888× Neelum	-38.09**	-2.73	1.91	44.82**	-8.08**	-62.31 **	51.45*	-29.12**	30.33*	-8.03*	3.83
15	IC-15888× Neela	-42.85**	-4.32	-18.35*	31.03**	-8.08**	-76.01 **	2.57	-4.12	-10.46	-30.48**	7.37*
16	JRF-5× Shekhar	-19.04*	-8.19	-9.31	27.58*	2.69*	-73.56 **	36.02	4.12	-3.38	-46.65**	7.46**
17	JRF-5× Neelum	-19.04*	-16.49**	-27.39**	13.79	6.61**	-75.61 **	74.60**	8.37	28.64*	-27.70**	2.79
18	JRF-5× Neela	-19.04*	-23.66**	-9.58	62.06**	4.41**	-76.74 **	-0.95	-16.62*	5.81	-33.67**	2.62
19	Shekhar× Neelum	-12.71	2.04	-3.83	17.24	-8.08**	-48.59 **	45.02*	-8.37	51.90**	-9.88**	3.34
20	Shekhar× Neela	-12.71	-1.47	-7.39	20.68*	-6.86**	-70.64**	29.91	0	16.27	-11.22**	0.31
21	Neelum× Neela	3.19	-5.91	-17.26	10.34	-0.73	-50.52**	46.95*	-12.5	47.07**	-2.47	-1.41
	SE (d)	1.896	0.574	0.263	0.0256	1.642	2.48	20.71	0.526	1.157	0.288	0.963
	CD 5%	3.831	1.042	0.533	0.0516	3.318	5.012	41.855	1.046	2.338	0.582	1.963
	CD 1%	5.127	1.39	0.711	0.069	4.44	6.706	56	1.422	3.129	0.779	2.626

NB: * and ** Significant at 5% and 1% level of significance, respectively

For dough stage bud fly infestation % 10 cross combinations in F_1 and 14 in F_2 generation were found desirable with highly significant sca effects. Relatively higher estimates of sca effects were usually recorded in those crosses which involved diverse interacting parents. Swarnkar *et al.* (2003), Vishnu *et al.* (2005) also Tripathi *et al.* (2011) reported corroborative findings.

EC-1424×GS-234, EC-1424× IC-15888, EC-1424 × JRF-5, EC-1424 × Neela, JRF-5×Shekhar and Neelum ×Neela in both the generations had desirable significant sca effects which are indicative of the presence of additive x additive interaction effects. Similar results were also reported by Singh *et al.* (2013).

Heterotic response has often been expressed as a deviation of F_1 from the economic parental value (high yielding and well adopted cultivar) or superior parent. The degree of heterosis should preferably be measured as superiority of F_1 hybrids over the best commercial variety **(Table 4).** Such estimate, in real sense, decides whether the hybrid is worth exploiting or not.

The degree and direction of heterosis response varied not only from character to character but also from cross to cross. In the present investigation, character shows dough stage bud fly infestation shows heterosis over superior parent ranged from –99.03 (EC-1424× JRF-5) to -48.59 (Shekhar×Neelum) in F_1 generation. Out of 21 crosses 20 crosses showed negative significant economic heterosis. The best five crosses are EC-1424× JRF-5, EC-1424× Neela, GS-234 × IC-15888, GS-234×JRF-5 and IC-15888×Shekhar. Only one cross showed positive significant (EC-1424× Shekhar). In seed yield per plant shows the heterosis over economic parent ranged from 28.64 (JRF-5×Neelum) to 51.90 (Shekhar×Neelum) in F_1 generation. In all crosses, six cross as showed positive and significant heterosis. The best two crosses were observed (Shekhar×Neelum and IC-15888×JRF-5). Similar results were also reported by Kumar and Singh (2002).

In sepal thickness character, 14 crosses showed positive and significant hetrosis crosses. In days to maturity character, significant and negative economic heterosis was found in 17 crosses. Similar results were also reported by Sharma *et al.* (2000) and Sharma *et al.* (2005). In Capsule/plant character, 8 crosses showed positive and significant hetrosis. Similar results were also reported by Kusalkar *et al.* (2002) and Kumar and Singh (2002).

In grain per capsule character, the significant and negative economic heterosis were found EC-1424×JRF-5, EC-1424×Neelum, GS-234×Shekhar, IC-15888×JRF-5, IC-15888× Shekhar and JRF-5×Neela and six crosses IC-15888×Neelum, EC-1424×JRF-5, EC-1424×Neela, GS-234×Shekhar, JRF-5×Neela and Neelum×Neela. Similar results were also reported by Singh *et al.* (2005).

In 1000-seed weight, 20 crosses were found significant and negative economic heterosis. Similar results were also reported by Sharma *et al.* (2005).

In oil content character, only four crosses (GS-234×Shekhar, IC-15888×Shekhar, IC-15888×Neela and JRF-5×Shekhar) showed positive and significant heterosis. Similar results were also reported by Ratnaparkhi *et al.* (2005) and Singh *et al.* (2005).

IV. CONCLUSION

Combining ability analysis was carried out in linseed during *rabi* 2020-21. The experimental material included in present study consisting 49 genotypes comprising 7 parents and 21 F_1 and 21 F_2. The study revealed the importance of non-additive gene action in the inheritance of all the traits and stresses the need for its exploitation either through heterosis breeding or suitable population improvement programme.

On the basis of *per se* performance and gca effects good general combiners common in both F_1 and F_2 generations were Neela for days to flowering and bud length, IC-15888, sepal thickness, maturity duration and Grain/capsules. Shekhar and Neela, for dough stage bud fly infestation %, Neela, for test weight GS-234 and Neelum and for oil content Shekher. The best five crosses are EC-1424× JRF-5, EC-1424× Neela, GS-234 × IC-15888, GS-234×JRF-5 and IC-15888×Shekhar. Only one cross showed positive significant (EC-1424× Shekhar). In seed yield per plant shows the heterosis over economic parent ranged from 28.64 (JRF-5×Neelum) to 51.90 (Shekhar×Neelum) in F_1 generation. In all crosses, six cross as showed positive and significant heterosis. These crosses combinations could be utilized for further use in breeding programme for improvement in yield of linseed.

REFERENCES

[1] Anonymous 2013. Annual report of Linseed: 2012-13, Publ. Project Coordinating Unit (Linseed), C. S. Azad University of Agriculture & Technology, Kanpur. Executive Summary, i.

[2] Bhateria, S., Sood, S. and Pathania, A. 2006. Genetic analysis of quantitative traits across environments in linseed (*Linum usitatissimum* L.). *Euphytica.* 150(1-2): 185-194.

[3] Cockerham, C. C. 1961. Implication of genetic variance in a hybrid breeding programme. Crop Sci. 1: 47-52.

[4] Dakhore, S. R., Narkhede, M. N. and Khargade, P. W. 1987. Heterosis in relation to combining ability effects in linseed (*Linum usitatissimum* L.). PKV Res. J. 11(1): 7-12.

[5] Foster, R., Pooni, H. S. and Mackay, I. J. 1998. Quantitative analysis of *Linum usitatissimum* L. crosses for dual purpose traits. J. Agric. Sci. 131(1): 285-292.

[6] Gauraha, D., Rao, S. S. and Pandagare, J. M. 2011. Genetic analysis of yield and yield attributing characters in linseed (*Linum usitatissimum* L.). Asian J. Bio Sci. 6(1): 16-22.

[7] Hayes, H. K., Immer, F. F. and Smith, D. C. 1956. Methods of Plant Breeding. McGraw Hill Book Publishing Company, Inc., New Delhi.

[8] J. and Meena, H. P. 2013. Heterosis and combining ability for yield and yield component characters of newly developed castor (*Ricinus communis* L.) hybrid. The Bioscan. 8(4): 1421-1424.

[9] Jain, A. and Rao. S. S. 2004. Study of combining ability by diallel cross analysis in linseed (*Linum usitatissimum* L.). J. Agril. Issues. 9(1&2): 109-111.

[10] Jhajharia, S., Choudhary, P., Jhajharia, A., Meena, L.K. and Singh, D. 2013. Heterosis and combining ability in safflower (Carthamus tinctorius L.) germplasm lines. The Bioscan. 8(4): 1453-1460.

[11] Kansal, K. K. and Gupta, S. C. 1981. Note on heterosis in linseed. Indian J. Agric. Sci. 51(9): 680-687.

[12] Kempthorne, J. W. 1957. An introduction to genetic studies (Ed.) J. Wiley and Sons, Inc. New York, USA.

[13] Khorgade, P. W., Narkhede, M. N., Ingle, W. S., Raut, S. K. and Dakhore, S. R. 1990. Combining ability for yield, oil content and related components in linseed. *J. Maharashtra Agric. Univ*. 15(3): 281-283.

[14] Khorgade, P. W., Sakhre, B. A., Narkhede, M. N. and Raut, S. K. 1993. Genetic analysis of seed yield and its attributes in linseed. Biovigyana. 19(1-2): 7-10.

[15] Kurt, O. and Evans, G. M. 1998. Genetic basis of variation in linseed (*Linum usitatissimum* L.) cultivars. Turkish J. Agric. For. 22(4): 373- 379.

[16] Mishra, R. K., Marker, S., Bhatnagar, V. and Mahto, D. 2013. Combining ability and heterosis for seed yield and its component in linseed (*Linum usitatissimum* L.). Adv. Plant Sci. 2(1): 44-47.

[17] Ramesh, M., Lavanya, C., Sujatha, M., Sivasankar, A., Aruna Kumari, and applications; Short Communications, Symposium; Ludhiana, pp. 52-53.

[18] Rao, S. K., Singh, S. P. and Tawar, M. L. 1987. Heterosis for seed size and oil content in linseed. J. Oilseeds Res. 4(2): 242-245.

[19] Rao, S. S. and Rastogi, N. K. 2007. Combining ability for seed yield and its attributes in linseed (*Linum usitatissimum* L.). J. Oilseeds Res. 24(1): 68-71.

[20] Ratnaparkhi, R. D., Dudhe, M. Y., Gawande, N. D. and Bhongle, Reddy, M. P., Arsul, B.T., Shaik, N. R. and Maheshwari, J. J. 2013. Estimation of heterosis for some traits in linseed (*Linum usitatissimum* L.). J. Agri and Vet. Sci. 2(5): 11-17.

[21] Rede, A. P. 1999. Genetic analysis of yield and yield attributing characters in linseed (*Linum usitatissimum* L.). M.Sc. Thesis, Indira Gandhi Krishi Vishwavidyalaya, Raipur, C.G.

[22] S.A. 2005. Combining ability study in linseed through line × tester analysis. Ann. Plant Physiol. 19(1): 99-102.

[23] Saraswat, A. V., Kumar, S., Kumar, S., Verma, M. M., Virk, D. S. and Chahal, G.S. 1993. Heterosis and inbreeding depression in some early hybrids of linseed. Heterosis breeding in crop plants- theory and applications; Short Communications, Symposium; Ludhiana, pp. 52-53.

[24] Sharma, R., Tiwari, S. K., Singh, P. and Kant, R. 2005. Heterobeltiosis and inbreeding depression in linseed. Agric. Sci. Digest. 25(1): 35- 37.

[25] Singh, P. K., Srivastava, R. L., Narain, V. and Dubey, S. D. 2009. Combining ability and heterosis for seed yield and oil content in linseed *(Linum usitatissimum* L.). Indian J. Agri. Sci. 79(3): 229-232.

[26] Singh, R. K. and Chaudhary, B. D. 1977. Biometrical methods in quantitative genetic analysis. Kalyani Publishers, Ludhiana.

[27] Singh, R. S., Singh, S. and Chaudhary, R. K. 1983. Heterobeltiosis in relation to per se performance and effects of general combining ability in linseed (*Linum usitatissimum* L.). Pre-congress Scientific meeting on genetics and improvement of heterotic systems, Tamil Nadu Agril. Uni., Coimbatore.

[28] Singh, V., Chauhan, M. P., Kumar, K. and Singh, R. B. 2006. Heterosis for yield and yield attributes in linseed (*Linum usitatissimum* L.). Farm Sci J. 15(1): 29-31.

[29] Singh, V., Pachauri, O. P. and Tiwari, S. N. 1987. Combining ability studies in linseed (*Linum usitatissimum* L.). Indian J. Genet. 47(2): 171-178.

[30] Srivastava, R. L., Srivastava, S. K., Dubey, S. D. and Kerkhi, S. A. 2004. Heterosis and combining ability estimates in linseed under salt affected soil. Indian Agric. 48(3&4): 193-197.

[31] Tak, G. M. and Gupta, V. P. 1993. Studies on heterosis in linseed. Indian J. Agri. Res. 27(4): 181-184.

[32] Thakur, H. L., Rana, H. D. and Sood, O. P. 1987. Combining ability analysis for some quantitative characters in linseed. Indian J. Genet. 47(1): 6-10.

[33] Verma, A. K. and Mahto, J. L. 1996. Hybrid vigour in linseed (*Linum usitatissimum* L.) for yield and its attributes under rainfed and irrigated environments. J. Tropical Agri. 34(1): 54-57.

A Bio-dynamic Agriculture Model based on Rock Dust: A Case Study in Alto Alegre, Roraima, Brazil

Cristiano De Angelis

Skema Business School, France

Received:- 06 April 2025/ Revised:- 13 April 2025/ Accepted:- 19 April 2025/ Published: 30-04-2025

Abstract— *The success in the use of rock dust as a non-chemical fertilizer, being a great vitoria of biodynamic agriculture, has led to an interesting amount of investigations, mainly with a highly theoretical bias, often without discussing common trade-offs in agriculture such as the fact that the larger soil breathing increases the problem of potential carbon loss and the highest sodium concentration increases the problem of the risk of soil sodification.*

Researchers found that the correction of soil nutritional deficiencies can also be achieved with the application of finely ground rock types such as natural phosphates, gypsum, mafic and ultramafic rocks e mais recentemente as silicate rocks, and more recently silicate rocks, due to their abundance and the ease with which they can be found in the form of fine residues from the moulding process in the canteras. The idea of these researchers is that the carrier rocks are full of nutrients, particularly K, Ca and Mg, and therefore laboratory tests are not necessary.

In other words, most researchers avoid joint analysis (rocks and soils), in particular geochemicals and mineral analysis, because the easiest part of the work is to show, through literature reviews, the great advantages of sostenible fertilizers, in particular as regards highly degraded soils, putting special emphasis on strong soil remineralization and soil pH balance, in contrast to the high cost and harmful impact of chemical fertilizer industry on Global Global Warming, in proportion similar to fuel fuels.

In addition they do not consider rock dust as a Biodinamic Homemade fertilizer. The difficulty of cooperatives engaging in the acquisition of crushing machines depends on a closer relationship with agricultural entitles to analyze both rocks and soils (compatibility examination) besides the union among farmers for formation in this "novelty" and subsequent construction of crushing machines in their own farms.

For this reason, the research question is how culture relates to knowledge and intelligence in order to know what type of culture we have to build for effective Bio-dynamic agriculture.

Therefore, this work brings two research models that feed each other.

In addition to the Culture-Knowledge-Intelligence (CKI) model, this article presents a Bio-dynamic Agriculture model, a mature way of better using the resources available on the farm itself. The study concluded that this model is useful for small farmers to learn, through cooperatives, home-made farming practices, such as rock dust as a new fertilizer mixed or not with cattle manure.

Keywords— Family farming, cooperatives, knowledge management, cultural intelligence, local solutions.

I. INTRODUCTION

1.1 Soil remineralization using rock dust:

In addition to the benefits outlined in the abstract, rock dust has been shown to increase the cation exchange capacity (Anda et al., 2015) and water-holding capacity of sandy soils (Kahnt et al., 1986). However, many rock dusts are either inefficient or contain potentially toxic elements in harmful levels. As a result, the effectiveness of applying finely ground rocks to tropical soils largely depends on their chemical and mineralogical composition, soil deficiencies, and the specific requirements of the crops being grown (van Straaten, 2017).

This advantage of rock dust over chemical fertilizers is particularly evident in highly weathered soils found in tropical regions, where traditional soluble fertilizers may be expensive or unavailable (Swoboda, Döring, & Hamer, 2022). An analysis by Swoboda, Döring, and Hamer (2022) of 48 crop trials demonstrated the potential of rock dust as an alternative source of potassium (K) and a multi-nutrient soil amendment for tropical soils, while the benefits for temperate soils remain unclear. Positive outcomes were particularly observed with mafic and ultramafic rocks such as basalts and rocks containing nepheline or glauconite. Among various silicate rock powders (PRS), basalt powder stands out. Basalts, being igneous rocks with a mafic composition, are rich in magnesium (Mg) and iron (Fe) silicates and have a basic pH. These rocks also provide essential nutrients for plant nutrition, including phosphorus (P), potassium (K), calcium (Ca), and several micronutrients (Swoboda, Döring, & Hamer, 2022).

Viana, Caetano, and Pontes (2021) describe a technique that combines intermediate doses of basalt powder with larger doses of cattle manure. While various methods are used, the most effective approach was found to be the combination of rock dust with another type of fertilizer. Da Silva et al. (2017) emphasize that integrating rock powders with organic materials that support biological activity can influence the mineral alteration process. However, there is limited knowledge on how materials affect the dissolution of ground rocks, particularly basalt rock powder.

During composting, the nitrogen cycle plays a crucial role in determining compost quality (Hoang et al., 2022). This article will discuss strategies for mitigating nitrogen loss. Some researchers, however, present findings without thorough research, such as lab tests or real-world farm applications. Ramos et al. (2022) suggest that combining organic fertilizers with rock powder can meet the nutritional needs of both macro and micronutrients, with application costs of rock powder being significantly lower (<60%) and having long-term fertility benefits. Specifically, corn and bean plants grown in soils enriched with basalt dust yielded up to five times more than crops without basalt dust (Conceição et al., 2022).

Similarly, Bauwhede et al. (2024) report that rock dust helps reduce nutrient leaching by providing a slow, sustained release of nutrients into the soil. However, this depends on the mineralogy of the rock, soil acidity, and the testing methodology. Grecco et al. (2016) highlight that the low processing costs and the need for alternative fertilizers support the practice of using ground rocks on soil. Nevertheless, studies on this subject are limited, and the nutrient release rate remains unclear as different rocks react differently to weathering, influencing nutrient availability.

Dos Santos et al. (2016) explain that nutrient release from rock dust occurs more slowly compared to chemical fertilizers. While this slow release is an advantage in some cases, it can also be a disadvantage, as it extends the process and requires larger quantities of material to be applied to the soil.

Lopes-Assad et al. (2006) found that the fungus Aspergillus niger is effective in solubilizing phosphate rocks through the production of organic acids. In the treatment with Aspergillus niger, pH fluctuated over time, with increased acidity leading to higher potassium (K) solubilization rates. However, when treating alkaline ultramafic rocks with Aspergillus niger, the acidity decreased, resulting in a reduced K solubilization rate.

To counter soil acidity, it is common practice to lime the soil with calcium and/or magnesium carbonates (such as calcite and dolomite). These minerals react with hydrogen ions released by the soil water, as well as carbon dioxide and aluminum in the form of hydroxide, thereby mitigating aluminum toxicity (Goulding, 2016).

The application of rock dust depends significantly on the crop being cultivated. Some crops, such as lettuce, require a high concentration of nutrients in the short term, and therefore, basalt may not be ideal for these situations.

Hanish et al. (2024) found that applying up to 100g of basalt filler powder to both tested soils did not result in any significant increase in lettuce yields. The yields observed without soluble fertilizer (averaging 50g per pot of lettuce) were nearly four times smaller than those achieved with fertilizer treatments. Lettuce cultivation requires high doses of soluble inputs to meet the crop's nutritional demands within its short production cycle. As a result, basalt powder, with its low nutrient concentration, was unable to fulfill the crop's short-term needs.

Guimarães et al. (2020) found that banana orchards fertilized solely with mineral sources produced higher fruit yields compared to those fertilized with organic-mineral sources. However, the organic-mineral fertilization resulted in lower soil acidity and higher availability of phosphorus (P) and potassium (K). It was also observed that excessive potassium in the soil could cause nutritional imbalances in the plants, potentially reducing their productive potential. Consequently, further studies on banana fertilization strategies are necessary to improve nutritional balance.

It is important to approach the overestimation of rock dust as a fertilizer in Brazil with caution, as noted by Viana, Caetano, and Pontes (2021). They acknowledge that rock dust holds significant potential for Brazilian agriculture but is still underexplored. More research is required, particularly focusing on the agronomic effectiveness of rock dust when combined with animal manure (Viana et al., 2021).

According to Organicospro (2018), a well-known type of ground rock is limestone, which is rich in calcium carbonate (calcite limestone) or calcium magnesium carbonate (dolomitic limestone). In contrast, basalt powder is rich in silicate minerals that provide silicon to the soil—a crucial nutrient for promoting plant health and boosting productivity. These and other examples underscore the role of basalt powder in restoring degraded and leached soils, stimulating soil biology, and enhancing overall production. Some advantages of biomineralization include:

- Replenishing nutrients in weak and impoverished soils
- Reducing acidity over time
- Improving soil structure by enhancing oxygen content
- Lowering chemical fertilizer costs
- Increasing seed germination
- Enhancing the growth of roots and plant aerial parts
- Thicker stems and bark
- Creating a protective leaf film against diseases, wind, and frost
- Increasing durability post-harvest
- Providing a greater quantity of nutrients

Batista (2016) applied basalt rock powder in varying quantities, with and without the addition of limestone, to soil samples. In samples with limestone, potassium levels increased compared to those without limestone, and the pH was higher. Soil pH correction was less pronounced when limestone was not included in the treatment. It is important to note that soil re-acidification is a slow process, and superficial reapplication of limestone is sufficient to correct it. The study concludes that while soybean yields showed a modest but positive response to limestone reapplication (an average yield increase of 252 kg ha^{-1} $year^{-1}$), corn yields were less affected (Hammerschmitt et al., 2021).

Among the aluminosilicate minerals found in rock dusts (RDs) are orthosilicates (e.g., olivine), inosilicates (e.g., pyroxenes like diopside, amphiboles like hornblende), tectosilicates (e.g., orthoclase, plagioclase, nepheline, leucite), and phyllosilicates (e.g., biotite and muscovite) (Calabrese et al., 2022; Swoboda et al., 2022; van Straaten, 2006). RDs can serve as an alternative to conventional liming, but unlike lime, they have a lower acid-neutralizing capacity (ANC) and release their alkalinity more gradually. Additionally, they provide a range of nutrients, including calcium (Ca), magnesium (Mg), potassium (K), phosphorus (P), and sulfur (S) (De Vries et al., 2021; Ramos et al., 2022; Swoboda et al., 2022).

Swoboda, Döring, and Hamer (2020) found that several rock modifications significantly improve the agronomic effectiveness of silicate rock powders (SRPs). Enhanced weathering of SRPs could also sequester substantial amounts of CO2 from the atmosphere, and supplying silicon (Si) could enhance plant resistance to a broad spectrum of biotic and abiotic stresses.

More research is needed to fully understand the use of silicate rock powders (SRPs) when combined with limestone, chemical fertilizers, or animal manure. Particularly, studies should focus on the type of rock, the type of soil, the crop being cultivated, and the application quantity, as illustrated in Figure 1 below:

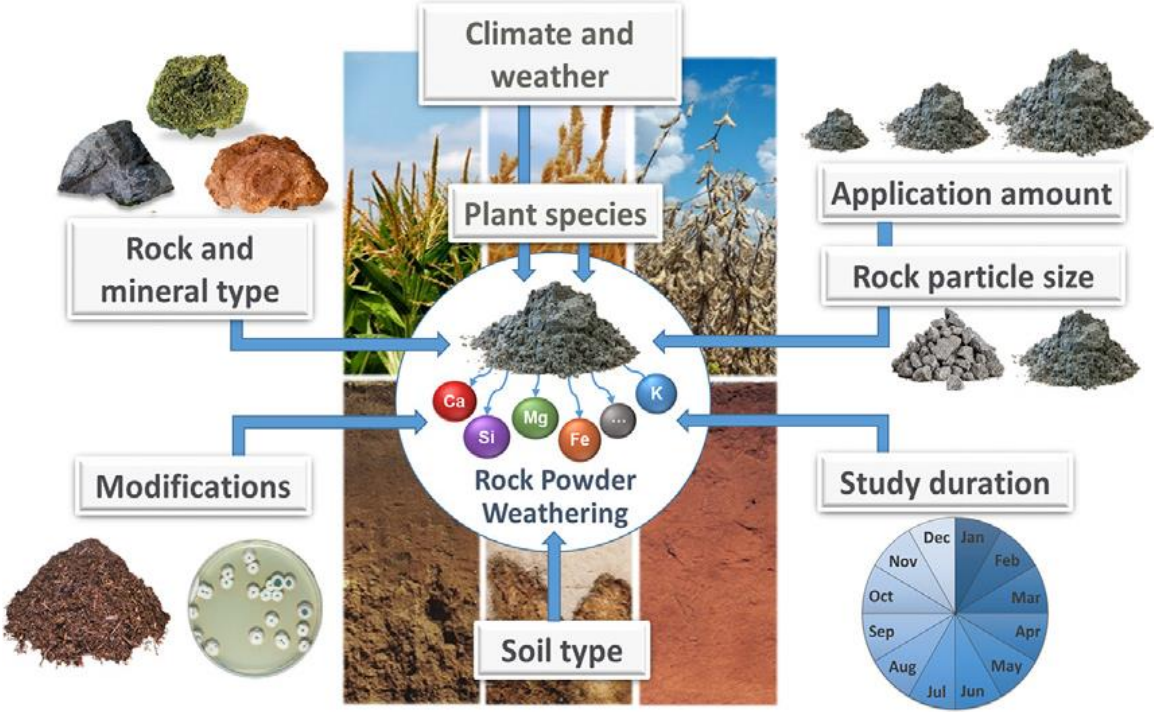


FIGURE 1: Factors influencing the use of silicate rock powders - SRPs (Swoboda Döringb & Hamera, 2022)

Bergmann and Holanda (2014) explain that when considering the use of a rock as a soil remineralizer, it is essential to investigate these processes through petrography. This method enables the identification of minerals, their texture, crystallization order, grain size, and overall integrity. Additionally, the materials added to the soil must meet strict criteria, including limits on harmful or potentially harmful elements, such as toxic heavy metals, and components that could contribute to soil salinization or introduce inert minerals that may degrade soil structure, such as sodium and quartz compounds.

1.2 Best practices and lessons learned from bio-dynamic agriculture:

An excellent alternative to industrial agriculture, which is also in decline due to excessive mechanization, chemical manipulation, herbicide use, and neglect of environmental conservation, is bio-dynamic agriculture.

Bio-dynamic farming goes beyond organic farming by adopting a holistic, ecological, and ethical approach to farming, gardening, food, and nutrition. It is a way of living, working, and relating to nature and our vocations, fostering awareness of the uniqueness of each landscape and the inner development of individuals, as well as the collective growth of the community.

Common practices in bio-dynamic agriculture include striving for self-sufficiency in energy, fertilizers, plants, and animals; organizing activities around the natural rhythms of the environment; utilizing a diverse range of plants, fertilizers, and animals in a healthy manner; approaching work with seriousness, precision, order, and attention to detail; and maintaining punctuality in executing tasks (Paull, 2011).

Campbell and Watson (2012) and Raupp (2001) found that soil improvement in bio-dynamic agriculture is achieved through proper humus management. This includes applying well-fermented manure and organic fertilizers, practicing effective crop rotation, ensuring good soil functioning, implementing protective measures such as windbreaks, and using cover crops, green manures, and diversified crops instead of monocultures. Mixed cultivation is also emphasized to allow plants to support each other.

Boicean & Dent (2020) suggest that crops that deplete the soil, such as corn, potatoes, cabbage, and cauliflower, should alternate with crops that replenish the soil, such as legumes (peas, beans, clover, etc.). Additionally, deep-rooted crops should be alternated with shallow-rooted crops, and those requiring fertilizers should be paired with those that can thrive without them.

In line with bio-dynamic practices, FAO (2021) reports that sustainable agricultural practices can reduce damage to ecosystems and ensure food production despite challenges like climate change, extreme weather, droughts, and other disasters. These practices also contribute to the progressive improvement of land and soil quality.

1.3 Study on the Potential for the Use of Rock Dust in Roraima:

A noteworthy study on soil balancing in Roraima was conducted by Bergmann and Holanda (2014) as part of the broader project Geodiversity of the State of Roraima: Geology Program of Brazil (2014). The diverse soils, combined with climatic factors, terrain, and management limitations, allowed for the identification of six geographical units based on their potential for soil use and occupation in Roraima.

The most suitable area for soil balancing is the basic rock region (composed of Diabase, Basalt, and Gabro), which is dominated by vertical changes and includes red argisols, red oxisols, vertisols, chenosols, and nitisols. In Roraima, soils with low natural fertility and high acidity prevail, posing significant challenges to agricultural use. However, eutrophic soils, found in limited areas, have higher agricultural suitability and are more intensively used, though they still suffer from low technology adoption, as they are located in remote or rural settlement areas.

The lack of proper infrastructure also restricts productivity in Roraima, as the road network is insufficient for the timely delivery of supplies and efficient production flow. Additionally, labor is often underqualified, and public investments are lacking. Despite these challenges, the state's equatorial location provides favorable climatic conditions for agriculture, allowing most crops to yield better results compared to other Brazilian regions. Overcoming these challenges is crucial for economic growth, social inclusion of indigenous communities, and sustainable development. Sustainable agricultural practices, including rock balancing, play a key role in addressing these issues.

Agriculture in Roraima is mainly practiced in the La Sabana region, where various soil types, such as canosols (yellow, red-yellow, and red), argisols (red and yellow-red), and neosols (hydromorphic quartarene and organic, fluvic, and surface litholic), dominate. These soils are characterized by low base saturation, low cation exchange capacity, and high acidity. In particular, levels of interchangeable phosphorus are very low, requiring constant pH correction.

The most fertile soils in the state are found in the basic rock regions: the Pedra Preta Sill in the Uiramutã region, the volcanic rocks of the Apoteri formation near Nova Olinda, and the area around Taiano. The best areas within the basic volcanic rock domain are located in Vila do Taiano (northwest Roraima), Sierra de Nova Olinda (central Roraima), and near the indigenous community of Flechal in Uiramutã. These regions feature soils derived from basaltic rocks from the Apoteri formation, including red oxisols, organic slopes, and chernosols, along with nitisols associated with diabases, diorites, and gabbros of the Pedra Preta threshold. These areas exhibit a pronounced relief with strongly wavy topography under forest cover.

Figure 2 shows a taian diabase sample, collected in the municipality of Alto Alegre, and with strongly positive phosphomolibdate test.

FIGURE 2: Samples of diabase from Taiano (municipality of Alto Alegre) with strong positive phosphomolybdate test.

In addition to the municipality of Alto Alegre, in the municipality of Iracema, the presence of rare earth minerals, niobio, barium and phosphate are cited.

In Brazilian family agriculture, rock powders are used in consortium with waste of organic origin (animal manure and green fertilizer), and the farmer frequently produces their inputs through the composting process (possible thanks to a series of microorganisms), which allows increasing the efficiency of nutrient extraction.

The N is generally provided by the practice of green fertilizers, and plants such as Tithoniadiversifolia (honey flower) are also used, capable of adding K in proportions of up to 4.3% in leaves and ground stems added to the compost (Palm et al., 1997

Apud van Straaten, 2007) For such success it is important to consider the use of rock powders within the soil-plastic system, which includes the entire microbiota of the soil. and particularities of plant roots extraction systems (Mundstock, 2013).

According to investigation indicative results, rock dust can be applied to any crop, in particle sizes that range between 0.105 and 4.0 mm, similar to limestone, by casting or use of machines. The amounts vary according to the ground and the cultivation in question, oscillating between 0.5 and 8 tons/hectare. Due to its already established use and performance in agronomic trials, it can be affirmed that in Brazil, the volcanic rocks of basic composition of the Serra Geral formation (basaltos and diabasas of the southern, southeast and central-west regions) have good potential for balancing combined with the fact that they are often available as fine crushers. While these rocks have relatively low silica contents, they have high contents of CA, mg and faith that are associated with mineral structures with lower resistance to solubilization, being able to make them available in the short term, when added to the ground in the correct grain size.

Alkaline rocks, being rich in K, in addition to having volcanic terms with microcrystalline matrix, are very suitable for use in soil remineralization.

In Brazil, a Poços de Caldas phonolite is the only rock to date authorized for commercialization as adequate for use as an alternative to potassium chloride (KCL), a imported soluble fertilizer widely used in Brazilian agriculture (Cortes et al., 2009).

It is also important to note that the use of these rocks does not exclude the analysis of oligoements, to quantify micronutrients and potentially harmful elements (Bergmann and Holland, 2014).

1.4 The problem of excessive imports of chemical fertilizers in Brazil:

The rock dust brings to the plants a greater collection of elements. In addition to macronutrients P, k, calcium (ca), sulfur (s) and magnesium (mg), depending on the rock used, essential micronutrients can be offered, such as zinc (zn), copper (cu), iron (faith), manganese (mn), molybdenum (mo), boron (b), cobalt (co) and nickel (ni). In high solubility monoements fertilizers, the contribution is mostly limited to nitrogen (N), P and K macronutrients, although there are currently complex fertilizer formulas containing CA, Mg, S and micronutrients (mainly B and Zn). However, the negative aspect refers to the high solubility of the nutrients present in this type of input for Brazilian climatic conditions.

Thus, soil remineralization techniques are considered alternative routes to fertilize exhausted soils due to the loss of nutrients. Its importance is great in countries such as Brazil, which imports around 65% of the raw materials necessary to manufacture fertilizers and presents a worrying demand projection on production in this sector, which is expected to reach 83% in 2025 (Bergmann and Holland, 2014).), as shown in Figure 3.

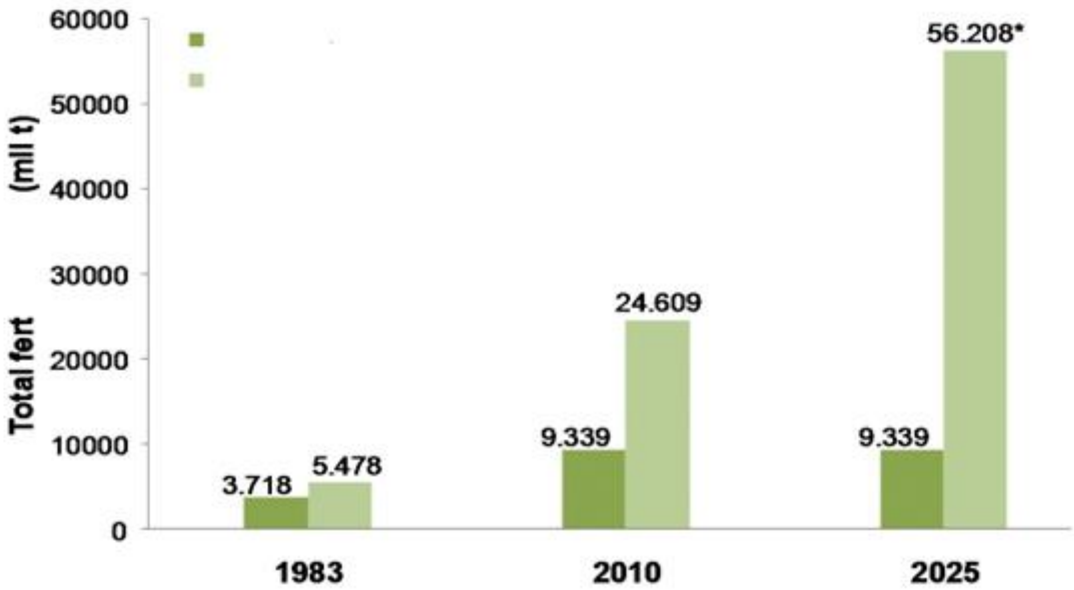


FIGURE 3: Production and demand graph of fertilizers in Brazil. Adapted from Martins (2013).
Source: ANDA (2011). Mbagro Project.

According to Goulart et al. (2023), the Novos Campos region in Roraima is home to magmatogenic phosphate mineralizations associated with the anorthosite-manager-chanockite-shanite (AMCG) association. Additionally, the region features magmatichydrothermal phosphate deposits and minerals containing rare earth elements (ETR) linked to alkaline volcanic-reputonic complexes. The Gabroanorthosite units of the AMCG Mucajaí association are identified as the most significant phosphate resource in the region.

Brazil's heavy dependence on fertilizer imports makes the country vulnerable to fluctuations in the international market, such as exchange rate variations, changes in trade policies, and logistical challenges. These factors could disrupt the consistent supply of fertilizers that Brazilian farmers rely on, potentially compromising agricultural production and food security. Fertilizer imports involve long distances and necessitate adequate infrastructure for transportation, storage, and distribution. High logistics costs, including maritime transport, storage, and internal distribution, contribute to the increased final price of imported fertilizers. This, in turn, negatively affects the economic viability of imports, making products more expensive for farmers and reducing their competitiveness. The high fiscal burden, including ICMS taxes on fertilizer imports, further impacts the Brazilian agricultural sector and food security, ultimately leading to higher food prices for consumers.

In response to this issue, the Brazilian federal government introduced the National Fertilizer Plan (PNF) in November 2022, aimed at reducing the country's dependency on fertilizer imports. The plan is intended to guide the fertilizer sector through 2050. However, cultural factors continue to constrain the sector, with farmers remaining reluctant to adopt biodynamic (homemade) practices. Small-scale farmers face challenges due to a lack of education on alternative methods, while medium and large-scale farmers are already accustomed to the importation of chemical fertilizers.

Moreover, there is a lack of legislation or government initiatives that facilitate access to non-chemical fertilizers, such as the construction of rock crushers, soil physico-chemical studies, and access to scientific research from Embrapa, the Geological Service of Brazil (SGB), and other related institutions.

Law No. 12,890, passed on December 10, 2013, regulates the inspection and control of the production and marketing of fertilizers, correctors, inoculants, biofertilizers, remineralizers, and substrates for plants. It establishes important guidelines for these products' use in agriculture.

Regulatory Instruction No. 39, dated August 8, 2018, outlines definitions, requirements, specifications, guarantees, product registration procedures, authorizations, packaging, labeling, fiscal documentation, advertising standards, and tolerances for mineral fertilizers intended for agriculture.

The Ministry of Agriculture, Livestock and Supply (MAPA) has standardized the production, registration, and marketing of remineralizers, commonly known as "rock dust." This ground and sifted rock is used to enhance the physical and chemical quality of soil. While it differs from common fertilizers in solubility and concentration, both types of fertilizers offer complementary effects. With the new legislation, consumers can now verify the quality of these products, which will be officially registered with MAPA.

Regulatory Instructions 5 and 6, published in the official gazette on Monday (14), establish several requirements for manufacturers to ensure the provision of quality and safe products. These regulations also outline the rules that must be followed during the registration process.

The regulation of remineralizers represents a valuable alternative for Brazilian farmers, who already depend on limestone and mineral fertilizers to restore soil fertility. This long-standing demand from the sector, particularly among organic producers who avoid mineral fertilizers but are open to using "rock dust," has now been addressed through new legislation, as noted in the Official Gazette of the Union.

II. RESEARCH METHODOLOGY

This study uses the literature review methodology in an integrated way to better understand the impact of culture on knowledge and intelligence.

Snyder (2019) states that literature review as a research method is more relevant than ever. Traditional literature reviews present a careful menu of thoroughness and rigor and are carried out on an ad hoc basis rather than following a specific methodology.

In the article, it will be argued that the potential for theoretical and practical contributions using the literature review as a method will be advanced to clarify what a literature review is, how you can use it, and what criteria should be used to assess its quality.

Of course, there are some guidelines for conducting literature reviews that suggest different types of reviews, such as narrative or integrative reviews (e.g., Baumeister & Leary, 1997; Wong, Greenhalgh, Westhorp, Buckingham, & Pawson, 2013), systematic reviews and meta-analysis (e.g., Davis, Mengersen, Bennett and Mazerolle, 2014; Liberati et al., 2009; Moher, Liberati, Tetzlaff and Altman, 2009) or integrated reviews (e.g., Torraco, 2005). There have also been some intentions to develop specific guidelines for business or management research (e.g., Palmatier, Houston, and Hulland, 2018; Tranfield et al., 2003).

This article carries out an integrated review of the literature on silicate rock powders (SRPs), biological fixation of nitrogen, Culture, Knowledge management and Organizational Intelligence.

Integration occurs not only in the literature review itself, as the intersection between these concepts is demonstrated through different sources, but also through the two research models in which the constructs are present.

2.1 The Culture – Knowledge- Intelligence model:

Kroeber (1949) asserts that what distinguishes humans from animals is culture. Since humans transcend their organic limitations, culture becomes an accumulative process, with each individual building upon the experiences of those before them, thereby contributing to the cultural development.

- Culture, rather than genetics, shapes behavior and dictates actions.
- Humans age in accordance with the cultural norms of their society. Their instincts are partially suppressed due to the extensive "evolutionary process" they undergo.
- Culture is a cumulative process, forged from the historical experiences of past generations. This process either restricts or encourages an individual's capacity for creative or non-creative action.

Building upon these foundational concepts, the Culture-Knowledge-Intelligence (CCI) model is developed, as depicted in Figure 4.

The premises of the CCI model are:

a) Culture is composed of the beliefs, values, assumptions, and traditions of a society (SCHEIN, 2010). (ii) The central thesis is that for education to achieve its objectives, the curriculum must be restructured or reformulated around the four pillars of learning: learning to know, learning to do, learning to live together, and learning to be (SMITH, 2018). (iii) The three pillars of intelligence are: prediction, strategy, and action (ROTHBERG AND ERICKSON, 2004).

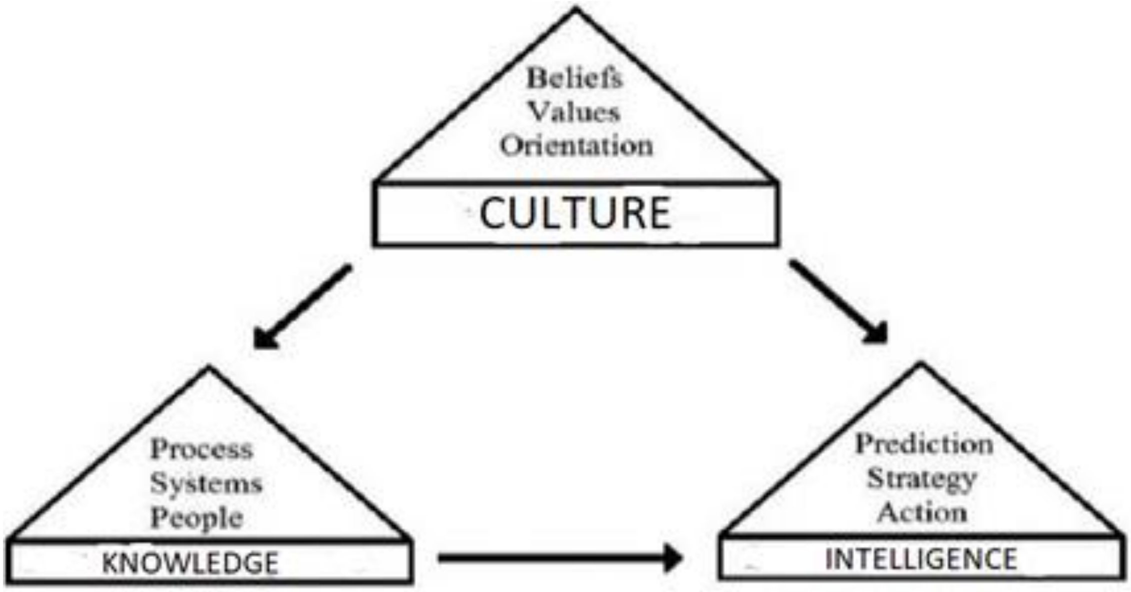


FIGURE 4: The Culture-Knowledge-Intelligence Model (adapted from Choo, 1998)

The CCI model is based on three hypotheses (Table I):

TABLE 1
ASSUMPTIONS OF THE CCI MODEL

Hypotheses	Sources	Results
Cultural has a positive impact on Knowledge	Leidner et al. (2006), Deal and Kennedy (1982) and Tweed and Lehman (2002) suggest that the way in which individuals perceive, organize and process information and the way in which they communicate with others and the way in which understand, organize and generate knowledge and solve problems, is related to culture.	SUPPORTED
Cultural has a positive impact on intelligence	Culture, more than genetics, determines behavior and determines its actions (KROEBER, 1949). Umuteme et al.(2023) posit that factors such as values, norms, beliefs and practices embedded in organizational culture significantly shape the overall project environment and affect team dynamics.	SUPPORTED
Knowledge has a positive impact on intelligence	Rothberg and Erickson (2004) maintain that knowledge is static and, ultimately, only has value if people use it (intelligence)	SUPPORTED

III. BIO-DYNAMIC AGRICULTURE MODEL

Due to their ability to create and apply collective knowledge, cooperatives have achieved surprising results in the local and national development process.

Silva et al. (2006) identified that 60 agricultural cooperatives showed a significant increase of profit in 130%.

Cooperative institutions can be found in various sectors of the economy, such as agriculture, health, credit, transport, education, etc. Of these sectors, the one with the best structure and to which great national and international importance is given is agriculture.

The idea of creating cooperatives in rural areas has enormous potential for the formation of social capital, as it promotes actions that aim to bring together not only the group of cooperative members but also the local community.

Figure 5 shows the Bio-dynamic family farming model.

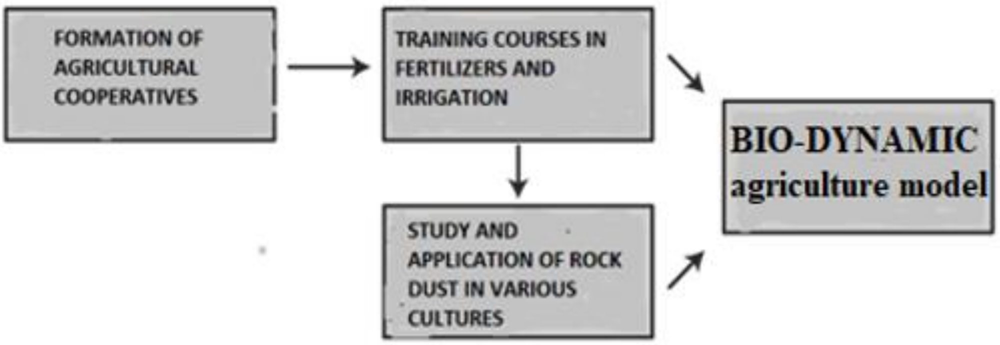


FIGURE 5: Bio-dynamic family farming model.
Fuente: Author, 2024

This Bio-dynamic agriculture model emphasizes that agricultural cooperatives are the foundation for this type of farming. However, for farmers to be motivated to unite and address their challenges, there needs to be a supportive culture that embraces training opportunities, especially on topics like fertilizers, which were discussed in the previous section. Thus, offering training courses, particularly on the use of rock dust, serves as a key foundation for the development and sustainability of Bio-dynamic agriculture.

Moreover, the Bio-dynamic model highlights that shifting the culture of small family farmers positively influences knowledge management practices within cooperatives and aids in the development and execution of the Farmers' Technical and Financial Assistance Plan (intelligence).

IV. CONCLUSION

Bio-dynamic agriculture relies on a mature cultural shift, as it encourages farmers to develop solutions based on the natural resources available on their farms. This article conducted a literature review on rock dust and biological nitrogen fixation to explore how such a culture can be cultivated. The article also proposed two interconnected models: the Culture-Knowledge-Intelligence model and the Bio-dynamic Agriculture model, which emphasize the creation and sharing of knowledge through cooperatives.

The study revealed the need for further research to address the challenges associated with dissolving silicate rock powders (SRPs) in various crops, considering both the quality and quantity of this material. There is also potential for exploring combinations of SRPs with limestone, animal manure, or even chemical fertilizers.

All of this research takes place in a collaborative setting between farmers and researchers, facilitated by cooperatives. Hence, it is crucial to understand the impact of culture on knowledge and intelligence in building a strong cultural foundation to apply relevant knowledge effectively.

AUTHOR CONTRIBUTION STATEMENT

Conceptualization, Methodology, Data curation, Writing- Original draft preparation, Visualization, Investigation, Validation, Writing- Reviewing and Editing.

CONFLICTS OF INTEREST

We have no conflicts of interest to disclose. All authors declare that they have no conflicts of interest.

REFERENCES

[1] Abreu, Katia (2016). Mapa regulamenta produção, registro e comércio do pó de rocha na agricultura. Disponível em https://www.gov.br/agricultura/pt-br/assuntos/noticias/mapa-regulamenta-producao-registro-e-comercio-do-po-de-rocha-na-agricultura

[2] Anda M, Shamshuddin J, Fauziah CI (2015) Improving chemical properties of a highly weathered soil using finely ground basalt rocks. Catena. 124:147-161

[3] Assad, Maria-Leonor & Rosa-Magri, Márcia & Erler, Greice & Antonini, Sandra. (2006). SOLUBILIZAÇÃO DE PÓ-DE-ROCHA POR ASPERGILLUS NIGER.

[4] Bamberg, A. & Martinazzo, Rosane & Silveira, Carlos & Pillon, C. & Stumpf, Lizete & Bergmann, Magda & van Straaten, Peter & Martins, Eder. (2023). Selected rock powders as sources of nutrients for soil fertilization and maize-wheat grain production in southern Brazil. The Journal of Agricultural Science. 161. 1-43. 10.1017/S002185962300062X.

[5] BATISTA, Nayra Thaís Ferreira; et al. Atributos químicos de um latossolo vermelho amarelo sob cultivo de soja e sorgo submetido ao uso de basalto moído. In: III Congresso Brasileiro De Rochagem, 2016, Pelotas. Anais p 240-247. Pelotas: Embrapa Clima Temperado; Brasília: Embrapa Cerrados; Assis: Triunfal Gráfica e Editora, 2016. 455 p.: il

[6] Bauwhede, R. D. Muys, B. Vancampenhout,K. Smolders, E. Accelerated weathering of silicate rock dusts predicts the slow-release liming in soils depending on rock mineralogy, soil acidity, and test methodology, Geoderma, 2024. Volume 441.

[7] Bellemare, M. F. Rising Food Prices, Food Price Volatility, and Social Unrest. American Journal of Agricultural Economics, 2015. 97(1), 1–21. http://www.jstor.org/stable/24476998.

[8] Boincean, B. Dent, D. Soil fertility – the only possible foundation for more sustainable agriculture. BIO Web of Conferences. 2020. 17. 00119. 10.1051/bioconf/20201700119.

[9] BRAZIL. Ministry of Agriculture, Livestock and Food Supply (2016) Normative Instruction 652 nº 05, 10 mar 2016. Diário Oficial da União, Brasília, DF, 14 mar.2016

[10] Calabrese S, Wild B, Bertagni MB, Bourg IC, White C, Aburto F, Cipolla G, Noto LV, Porporato A. Nano-to global-scale uncertainties in terrestrial enhanced weathering. Environmental Science and Technology. 2022.56(22):15261-15272.

[11] Camargo, C.K., J.T.V. De Resende, L.K.P. Camargo, A.S.T. Figueiredo & D.S. Zanin. Produtividade do morangueiro em função da adubação orgânica e com pó de basalto no plantio. Semina: Ciências Agrárias, 2012. v. 33, n. 1, p. 2985-2993

[12] Campbell, W.B.; Ortíz, S.L Integrating Agriculture, Conservation and Ecotourism: Societal Influences. Issues in Agroecology – Present Status and Future Prospectus. 2012.

[13] Choo, C.W. The Knowing Organisation, Oxford University Press, New York, NY.1998.

[14] Conceição, Lucas & Silva, Gutierres & Holsback, Heverton & Oliveira, Caroline & Marcante, Nericlenes & Martins, Eder & Santos, Fabio & Santos, Elcio. Potential of basalt dust to improve soil fertility and crop nutrition. Journal of Agriculture and Food Research. 2022. 10. 100443. 10.1016/j.jafr.2022.100443.

[15] Curtis, J., Luchese, A.V., & Missio, R.F. Application of soil remineralizer to poultry litter as an efficient and sustainable alternative for fertilizing maize crop. Journal of Plant Nutrition, 2022. 46, 423 – 438.

[16] DA SILVA, V.A; DA SILVA, L.E.S.F.; DA SILVA, A.J.N. et al. Solubility curve of rock powder inoculated with microorganisms in the production of biofertilizers. Agriculture and Natural Resources, v.51, p.142-147, 2017

[17] De Vries, W., de Jong, A., Kros, J., Spijker, J. The use of soil nutrient balances in deriving forest biomass harvesting guidelines specific to region, tree species and soil type in the Netherlands. 2021. For. Ecol. Manag. 479, 118591

[18] DOS SANTOS, Luiz Fernando; et al. Nutrição de milho após adição de sienito e substâncias húmicas. In: III Congresso Brasileiro De Rochagem, 2016, Pelotas. Anais p 427-434. Pelotas: Embrapa Clima Temperado; Brasília: Embrapa Cerrados; Assis: Triunfal Gráfica e Editora, 2016. 455 p.: il.

[19] Embrapa. 2016. Fixação biológica de Nitrogênio. Disponível em https://www.embrapa.br/tema-fixacao-biologica-de-nitrogenio

[20] FAO. An indispensable resource for everyone interested in food and agriculture. 2021. Available here: https://www.fao.org/newsroom/detail/an-indispensable-resource-for-food-agriculture-031121/en

[21] Goulding KWT (2016) Soil acidification and the importance of liming agricultural soils with particular reference to the United Kingdom. Soil Use Manag. 32:390-399.

[22] 691 https://doi.org/10.1111/sum.12270.

[23] Graveland, J., van der Wal, R., van Balen, J.H., van Noordwijk, A.J. Poor

[24] reproduction in forest passerines from decline of snail abundance on acidified soils. Nature 368, 1994. p.446–448.

[25] GRECCO, Matheus Farias; et al. Dinâmica de liberação de nutrientes em colunas de lixiviação a partir de rocha vulcânica hidrotermalizada, rincão dos francos, Bagé/RS. In: III CONGRESSO BRASILEIRO DE ROCHAGEM, 2016, Pelotas. Anais p 173-178. Pelotas: Embrapa Clima Temperado; Brasília: Embrapa Cerrados; Assis: Triunfal Gráfica e Editora, 2016. 455 p.: il.

[26] Guimarães, Gelton & Cantú, Rafael & Scherer, Ramon & Beltrame, André & Haro, Marcelo. (2020). Banana crop nutrition: insights into different nutrient sources and soil fertilizer application strategies. Revista Brasileira de Ciência do Solo. 44. 10.36783/18069657rbcs20190104.

[27] Hammerschmitt, R. K. Daniela Basso Facco, Gerson Laerson Drescher, Fábio Joel Kochem Mallmann, Fábio Benedito Ono, Leandro Zancanaro, Danilo "Rheinheimer" dos Santos, Limestone and gypsum reapplication in an oxisol under no-tillage promotes low soybean and corn yield increase under tropical conditions, Soil and Tillage Research,

[28] Hanisch, Ana Lúcia & Cantú, Rafael & Gonçalves, Guilherme & Justen, Juliane. (2024). Potencial do pó de basalto como remineralizador de solo em sistemas de produção de hortaliças. Agropecuária Catarinense. 37. 25-30. 10.52945/rac.v37i1.1788.

[29] Hoang Giang Hong, Bui Thi Phuong Thuy, Chitsan Lin, Dai-Viet N. Vo, Huu Tuan Tran, Mahadi B. Bahari, Van Giang Le, Chi Thanh Vu, The nitrogen cycle and mitigation strategies for nitrogen loss during organic waste composting: A review,

[30] Chemosphere, Volume 300, 2022,

[31] Ingole, Sangita. A Review on Role of Physico-Chemical Properties in Soil Quality. Chemical Science Review and Letters. 2015. 4. 57-66.

[32] Jacobsen, B.H., Latacz-Lohmann, U., Luesink, H., Michels, R., Ståhl, L. Costs of regulating ammonia emissions from livestock farms near Natura 2000 areas analyses of case farms from Germany, Netherlands and Denmark. J. Environ. Manage. 2019. 246, 897–908.

[33] Kahnt G, Pfleiderer H, Hijazi LA (1986) Effect of amelioration doses of rock powder and rock sand on growth of agricultural plants and on physical characteristics of sandy and clay soil. J Agron Crop Sci. 157(3):169-180

[34] Kroeber, A. L.The Concept of Culture in Science. The Journal of General Education. Vol. 3, No. 3 , pp. 182-196 (15 pages). Published By: Penn State University Press. 1949.

[35] Leidner, D.E., Alavi, M., & Kayworth, T.R. The Role of Culture in Knowledge Management: A Case Study of Two Global Firms. Int. J. e Collab., 2006. 17-40.

[36] via enhanced weathering. Appl. Geochem. 132, 105023

[37] Lindström K, Mousavi SA. Effectiveness of nitrogen fixation in rhizobia. Microb Biotechnol. 2020 Sep;13(5):1314-1335. doi: 10.1111/1751-7915.13517. 2019. Epub. PMID: 31797528; PMCID: PMC7415380.

[38] Luchese AV, Pivetta LA, Batista MA, Steiner F, Giaretta APS, Curtis JCD Agronomic feasibility of using basalt powder as soil nutrient remineralizer. Afr J Agric Res 17:487–497. 2021. https:// doi.org/ 10. 5897/ AJAR2 020. 15234

[39] Manning, D.A.C., Theodoro, S.H.. Enabling food security through use of local rocks and minerals. Extr. Ind. Soc. 7. 2020. 480–487

[40] Meriño-Gergichevich C, Alberdi M, Ivanov AG, Reyes-Díaz M (2010) Al3+-Ca2+ Interaction in plants growing in acid soils: Al-phytotoxicity response to calcareous amendments. J Soil Sci Plant Nut. 10:217-243.

[41] Moreira, F.M.S. & Siqueira, J.O. Microbiologia e bioquímica do solo. 2.ed. Lavras, Universidade Federal de Lavras, 2006. 729p.

[42] Organicospro (2018). Pó de rocha na agricultura orgânica. Disponível em https://www.organicospro.com.br/po-de-rocha-na-agricultura-organica

[43] Paull, John. Attending the First Organic Agriculture Course: Rudolf Steiner's Agriculture Course at Koberwitz. European Journal of Social Sciences – Volume Number. 21. 2011.

[44] PENHA, M. da N. C.; BERNARDI, A. C. de C.; SOUZA, G. B. de; NOGUEIRA, A. R. de A. (2016). EMBRAPA PECUÁRIA SUDESTE. Caracterização analitica e avaliação agronômica de rochas silicatadas como fontes de potássio. Disponível em https://www.embrapa.br/busca-de-publicacoes/-/publicacao/1065222/caracterizacao-analitica-e-avaliacao-agronomica-de-rochas-silicatadas-como-fontes-de-potassio

[45] Rafael RBA, Fernandez-Marcos ML, Cocco S, Ruello ML, Weindorf DC, Cardelli V, Corti G (2017) Assessment of potential nutrient release from phosphate rock and dolostone for application in acid soils. Pedosphere

[46] Ramos, C. G. James C. Hower, Erika Blanco, Marcos Leandro Silva Oliveira, Suzi Huff Theodoro. Possibilities of using silicate rock powder: An overview, Geoscience Frontiers, Volume 13, Issue 1.2022.

[47] Raupp, Joachim. Manure Fertilization for Soil Organic Matter Maintenance and its Effects Upon Crops and the Environment, Evaluated in a Long-term Trial. 2001.

[48] Schein EH. Organizational Culture and Leadership. San Francisco: Jossey-Bass Publishers. Sciences 21(1). 2010.

[49] Schuler, S. Conrad, R. Hydrogen oxidation activities in soil as influenced by pH, temperature, moisture, and season. Biol Fertil Soils. 1991. 12:127-130

[50] Silva DRS, Marchi G, Spehar CR, Guilherme LRG, Rein TA, Soares DA, Ávila FW (2012) Characterization and nutrient release from silicate rocks and influence on chemical changes în soil. Rev Bras Sci Solo. 36:951-962

[51] Silva MJ, Chaves LHG, Fernandes JD, Chaves, IDB (2015) Using MB-4 rock powder,

[52] 765 poultry litter biochar, silicate and calcium carbonate to amend different soil types. Aust J Crop Sci. 9(10):987-995. https://doi.org/10.4236/as.2015.611131.

[53] Silva, C. L. Lourenço, M. S. Pedro Filho, P. S. Capital Social e Cooperativismo no processo de desenvolvimento sustentável: estudo da cooperativa Bom Jesus - Lapa/ PR. 2006.

[54] Silva JV, Pede VO, Radanielson AM, Kodama W, Duarte A, de Guia AH, Malabayabas AJ, Pustika AB, Argosubekti N, Vithoonjit D, Hieu PT. Revisiting yield gaps and the scope for sustainable intensification for irrigated lowland rice in Southeast Asia. Agricultural Systems, 2022. 198, 103383

[55] Smith, P.Learning to know, be, do, and live together with in the cross-cultural experiences of immigrant teacher educators,Teaching and Teacher Education, 2018. Volume 69,

[56] Swoboda, P., D¨oring, T.F., Hamer, M. Remineralizing soils? The agricultural usage of silicate rock powders: A review. Sci. Total Environ. 807, 150976. 2022.

[57] Taylor, L.L., Driscoll, C.T., Groffman, P.M., Rau, G.H., Blum, J.D., Beerling, D.J.,Increased carbon capture by a silicate-treated forested watershed affected by acid deposition. Biogeosciences 18, 2021. 169–188.

[58] TEIXEIRA, P. C.; DIAS, R. C.; VENEU, D. M.; MONTE, M. B. M.; LOYOLA, J. A. D.; ZONTA, E. Eficiência relativa de rochas silicáticas cominuidas no fornecimento de potássio para plantas de milho. Embrapa Solos. Disponível em https://www.embrapa.br/busca-de-publicacoes/-/publicacao/1160268/eficiencia-relativa-de-rochas-silicaticas-cominuidas-no-fornecimento-de-potassio-para-plantas-de-milho

[59] Theodoro SH, Leonardos OH. The use of rocks to improve family agriculture in Brazil. An Acad Bras Cienc. Dec;78(4):721-30. doi: 10.1590/s0001-37652006000400008. PMID: 17143408. 2006.

[60] Tweed, R. G. and Lehman, D. R. "Learning Considered within a Cultural Context: Confucian and Socratic Approaches," American Psychologist, Vol. 57, No. 2, pp. 89-99. 2002. http://dx.doi.org/10.1037/0003-066X.57.2.89

[61] Umuteme, Oghenethoja & Adegbite, Waliu. Mitigating the impact of cross-culture on project team effectiveness in the Nigerian oil and gas industry: The mediating role of organizational culture and project leadership. Social Sciences & Humanities Open. 2023.

[62] van Diggelen, R., Bergsma, H., Bobbink, R., Sevink, J., Siebel, H., Siepel, H., Vogels, J., de Vries, W.Steenmeel en natuurherstel: een gelukkige relatie of een risicovolle combinatie?. 2019.

[63] Van Straaten, P. Farming with rocks and minerals: challenges and opportunities.

[64] An. Acad. Bras. Ciˆenc. 78, 2006. 731–747

[65] Van Straaten, P (2017) Rocks for crops in the world. In: III Brazilian Congress of Rochagem, Pelotas, 2017. Anais. Pelotas: Embrapa Clima Temperado, p.59-70.

[66] Vieira, R. F. Ciclo do nitrogênio em sistemas agrícolas. Brasília-DF: Embrapa, 2017. 163 p.

[67] Vicca S, Goll DS, Hagens M, Hartmann J, Janssens IA, Neubeck A, Peñuelas J, Poblador S, Rijnders J, Sardans J, Struyf E. Is the climate change mitigation effect of enhanced silicate weathering governed by biological processes?. Global change biology. 2022. 28(3): 711-726.

[68] WRITZL, T. C.; CANEPELLE, E.; STEIN, J. E. S.; KERKHOFF, J. T.; STEFFLER, A. D.; SILVA, D. W.; REDI, M. Produção de milho pipoca com uso do pó de rocha de basalto associado à cama de frango em latossolo. Revista Brasileira de Agropecuária Sustentável, v. 9, n. 2, 30 jun. 2019.

Prevalence of *Leptospira* spp. in Urine of Rats (*Rattus* spp.) in an Urban Village in the Philippines using LAMP and PCR Assays

Edlyn Mae N. Ciano

College of Veterinary Medicine, Benguet State University, PHILIPPINES

Received:- 07 April 2025/ Revised:- 15 April 2025/ Accepted:- 21 April 2025/ Published: 30-04-2025

Abstract— *Rats are recognized as key reservoirs and potential transmission sources of leptospirosis. Despite this, limited data exist on the prevalence of Leptospira spp. among rats in urban villages of the Philippines. This study aimed to assess the presence of Leptospira spp. in rats from an urban village in Benguet Province. Urine samples from 50 rats were analyzed using Loop-Mediated Isothermal Amplification (LAMP) and Polymerase Chain Reaction (PCR) assays. Results showed a Leptospira spp. detection rate of 30% using LAMP and 18% using PCR. DNA sequencing confirmed the presence of Leptospira interrogans serovar Icterohemorrhagiae, suggesting that rats may play a significant role in leptospirosis transmission in the study area. Diagnostic performance analysis revealed that LAMP and PCR had substantial agreement, with a Kappa coefficient of 0.677. Compared to PCR, LAMP demonstrated a diagnostic sensitivity of 100% and a specificity of 85.37%. These findings underscore the importance of continuous monitoring of rodent populations in urban settings and highlight the potential utility of LAMP as a rapid screening tool for leptospiral infections.*

Keywords— Prevalence, Leptospira spp., Rats, LAMP, PCR.

I. INTRODUCTION

Leptospirosis is a widespread bacterial zoonosis and a significant public health concern in Southeast Asia, including the Philippines. It is recognized both as a neglected zoonotic disease (NZD) and a neglected tropical disease (NTD), with increasing reports of outbreaks and severe cases globally. The disease primarily affects impoverished urban and rural populations, particularly in environments that support rodent-borne transmission.

Globally, leptospirosis accounts for over one million severe human cases annually, with the Philippines ranked among the countries with high incidence rates. Leptospirosis is endemic throughout the country and poses a serious health threat, especially in densely populated and flood-prone urban areas. Although most reported cases are concentrated in Regions VI, III, and the National Capital Region, the Cordillera Administrative Region (CAR) reports the highest case fatality rate (CFR) at 15%, despite a lower number of cases. This highlights the need for targeted surveillance and control strategies in this region.

Rats are the primary reservoir hosts for pathogenic *Leptospira* spp., playing a critical role in the transmission cycle. Previous studies have detected multiple *Leptospira* serovars in both humans and rats in the Philippines, suggesting zoonotic transmission. However, data on the status of *Leptospira* infection in rats, particularly in urban villages of La Trinidad, Benguet, remain scarce.

This study aims to determine the prevalence of *Leptospira* spp. in rats in an urban village in Benguet Province using molecular detection techniques—Loop-Mediated Isothermal Amplification (LAMP) and Polymerase Chain Reaction (PCR). The study also evaluates the diagnostic agreement and performance of LAMP relative to PCR. By identifying the circulating *Leptospira* strains and estimating infection rates in rats, the study contributes valuable baseline data that may inform local public health interventions and surveillance strategies.

II. MATERIALS AND METHODS

A total of 50 rats (*Rattus* spp.) were captured using Tomahawk live traps strategically deployed in Betag, La Trinidad, Benguet. Twenty-five rats were trapped within a five-meter radius of selected residential dwellings, while the remaining twenty-five were captured from garden areas within the same locality.

Captured rats were humanely sedated, and urine samples were collected via cystocentesis using a 3 mL syringe fitted with a 23-gauge needle. The urine samples were immediately transferred to 2 mL microcentrifuge tubes and stored at 4°C. DNA extraction was performed shortly thereafter, and the extracted DNA was stored under refrigeration for no longer than five days before molecular analysis.

Detection of *Leptospira* spp. was conducted using Loop-Mediated Isothermal Amplification (LAMP), following the protocol described by Koizumi *et al*. (2012), alongside conventional Polymerase Chain Reaction (PCR) assays. Urine samples that exhibited the darkest bands during agarose gel electrophoresis were selected for DNA sequencing to confirm and identify the *Leptospira* species present.

III. RESULTS AND DISCUSSIONS

3.1 Prevalence of *Leptospira* spp. in Rats:

The prevalence of *Leptospira* spp. in the 50 captured rats was determined using two molecular assays: Loop-Mediated Isothermal Amplification (LAMP) and Polymerase Chain Reaction (PCR). As shown in Table 1, LAMP detected *Leptospira* DNA in 15 of 50 samples, yielding a prevalence of 30% (95% CI: 17.3–42.7), while PCR detected 9 positive samples, corresponding to a prevalence of 18% (95% CI: 7.35–28.65).

TABLE 1
PREVALENCE OF *LEPTOSPIRA SPP*. IN RAT URINE SAMPLES (n = 50)

Test	Positive	Negative	Positivity Rate (%) (95% CI)
LAMP	15	35	30% (17.3–42.7)
PCR	9	41	18% (7.35–28.65)

The detection of *Leptospira* spp. in a considerable proportion of rats confirms their role as reservoirs and highlights ongoing environmental circulation of the pathogen. This finding is consistent with previous reports that have emphasized rats as important sources of *Leptospira* transmission in both humans and animals (Koizumi *et al*., 2012; Bonilla-Santiago & Nally, 2011).

Environmental and ecological factors may contribute to the relatively high prevalence observed. Betag is the only barangay in La Trinidad with predominantly flat terrain, potentially allowing the accumulation of contaminated water during rainy months. Floodwaters, which may contain *Leptospira*, are known risk factors for both rodent infections and human exposure (Yanagihara *et al*., 2007). Notably, this study was conducted during the rainy season (August to September), a period associated with peak leptospirosis incidence (Guerra, 2009; Per *et al*., 2011). Previous research has also shown that low-slope areas and flooding increase *Leptospira* prevalence in rodent populations (Ivanova *et al*., 2012).

The presence of infected rats near agricultural zones, such as the La Trinidad Strawberry Fields—currently being developed as an eco-tourism destination—raises concern for zoonotic transmission. Residents and tourists engaging in fieldwork or recreational activities may be exposed to contaminated soil or water, increasing the risk of infection. Additionally, with 35% of the population engaged in farming or livestock production, and an estimated dog population of 800, potential transmission to animals and humans is a significant concern. Leptospirosis in animals can result in reproductive losses and reduced productivity, leading to economic burdens for local farmers (Acha *et al*., 2003).

3.2 Diagnostic Comparison of LAMP and PCR:

The comparative diagnostic performance of LAMP and PCR is shown in Table 2.

TABLE 2
DIAGNOSTIC COMPARISON OF LAMP AND PCR RESULTS (n = 50)

	PCR Positive	PCR Negative	Total
LAMP +	9	6	15
LAMP –	0	35	35
Total	9	41	50

When compared to PCR, LAMP demonstrated a diagnostic sensitivity of 100% and specificity of 85.37% (95% CI: 74.55–96.19). The calculated Kappa coefficient was 0.677 (95% CI: 0.41–0.94), indicating substantial agreement between the two assays and an overall concordance of 88%.

The higher sensitivity of LAMP may be attributed to its ability to detect low concentrations of DNA. Table 3 shows the DNA concentrations in *Leptospira*-positive urine samples. The six samples that were LAMP-positive but PCR-negative had the lowest DNA concentrations, supporting the premise that LAMP performs better in low-DNA scenarios.

TABLE 3
DNA CONCENTRATIONS OF LAMP-POSITIVE URINE SAMPLES

Sample No.	DNA Concentration (ng/µl)	LAMP	PCR
6	46.5	+	+
8	120.0	+	+
11	232.0	+	+
13	88.0	+	+
18	17.9	+	+
20	76.0	+	+
21	83.0	+	+
22	76.0	+	+
41*	2.5	+	–
43*	28.0	+	–
45*	12.0	+	–
46*	9.5	+	–
48	51.0	+	+
49*	2.1	+	–
50*	24.1	+	–

Samples undetected by PCR

These findings align with previous studies reporting the superior sensitivity of LAMP over PCR in detecting *Leptospira* spp., especially in field conditions or low-resource settings (Koizumi *et al*., 2012; Dhama *et al*., 2014). LAMP's ability to operate at a constant temperature and its tolerance to common PCR inhibitors (e.g., hemoglobin, urea, salts) makes it a practical choice for rapid diagnostics in the field (Kaneko *et al*., 2007; Francois *et al*., 2011). Unlike PCR, which requires sophisticated equipment, LAMP is cost-effective, user-friendly, and suitable for decentralized testing in developing countries.

3.3 Identification of *Leptospira* Strain

Sequencing of the PCR-amplified product confirmed the identity of the pathogen as *Leptospira interrogans* serovar Icterohaemorrhagiae. This serovar is a well-known cause of severe leptospirosis in humans and dogs and is commonly associated with rats, particularly *Rattus norvegicus*, as primary reservoir hosts (Adler & de la Peña, 2009; Thiermann, 1981).

Studies have shown that rats infected with this serovar may become chronic carriers, shedding leptospires in urine for over seven months, thereby perpetuating environmental contamination (Thiermann, 1981). Transmission to humans and animals can occur through direct or indirect contact with infected urine or contaminated water or soil, especially during agricultural, recreational, or occupational activities (Wasin´ski & Dutkiewicz, 2013; Koizumi *et al*., 2009).

IV. CONCLUSION

This study is the first to molecularly detect the presence of *Leptospira* spp. in rats within an urban barangay in La Trinidad, Benguet, Philippines, providing novel insights into the epidemiology of leptospirosis in this area. The use of LAMP and PCR assays revealed that 30% and 18% of the 50 captured rats tested positive for *Leptospira* DNA, respectively. LAMP demonstrated higher sensitivity, effectively identifying positive samples with low DNA concentrations that PCR failed to detect. Diagnostic evaluation of LAMP against PCR indicated a sensitivity of 100% and specificity of 85.37%, with substantial agreement between the two assays ($\kappa = 0.677$), highlighting LAMP's potential as a practical and reliable diagnostic tool, particularly in low-resource settings and field conditions.

One of the most significant findings of this study was the identification of *Leptospira interrogans* serovar Icterohaemorrhagiae through DNA sequencing. This highly pathogenic strain is known to cause severe leptospirosis in both humans and animals. The identification of this serovar in rats suggests that it may be circulating within the local rodent population, particularly *Rattus norvegicus*, which are likely the primary reservoirs of the pathogen. Although sequencing was conducted on only one strongly positive sample, the result is consistent with previous reports of *Icterohaemorrhagiae* as a common cause of zoonotic transmission through rats.

The relatively high prevalence of *Leptospira* spp. detected in this study may be influenced by environmental and geographical factors in Betag, a low-lying area with relatively flat terrain, which may promote water stagnation and the persistence of leptospires, especially during the rainy season when the study was conducted. These conditions, combined with agricultural activities and backyard livestock farming, increase the risk of human and animal exposure to contaminated water and soil, underscoring the need for improved environmental management.

The findings of this study offer significant contributions to our understanding of the role of rats as reservoirs of *Leptospira* spp. in urbanizing agricultural settings and suggest a potentially underestimated public health threat in La Trinidad. However, there are limitations in this study, such as the small sample size and the lack of analysis of rat species, age, and sex, which have been shown to influence the carriage of *Leptospira* (Ivanova *et al*., 2012; Levett, 2001). Future studies with larger sample sizes, incorporating these variables, and including human and other animal populations, would provide a more comprehensive understanding of the transmission dynamics of leptospirosis in the region.

Based on the results of this study, several potential applications emerge. First, LAMP's high sensitivity and practical applicability in low-resource settings suggest it could be widely used for early diagnosis and surveillance of leptospirosis in rural and urban settings. This diagnostic approach could prove invaluable for rapidly detecting and controlling outbreaks, especially in areas where PCR testing is not available. Additionally, the identification of *Leptospira interrogans* serovar Icterohaemorrhagiae as circulating in rats underscores the need for ongoing molecular surveillance of the pathogen in rodent populations, which could help monitor the spread of this zoonotic disease. The use of LAMP in regular monitoring programs, alongside molecular surveillance of different Leptospira serovars, would help public health authorities assess and manage the risk of leptospirosis more effectively, ultimately contributing to better prevention and control strategies in endemic regions.

In conclusion, the results of this study highlight the need for continued vigilance and action to mitigate the risk of leptospirosis in La Trinidad, Benguet, and similar urban agricultural settings. The use of LAMP as a diagnostic tool, along with improved rodent control, environmental management, and public health education, will be crucial in reducing the burden of leptospirosis in both human and animal populations. Future research with larger sample sizes and broader surveillance will be essential for further elucidating the transmission dynamics of *Leptospira* spp. and for developing effective control strategies.

RECOMMENDATIONS

Based on the findings of this study, several recommendations are made to mitigate the risk of leptospirosis transmission in La Trinidad, Benguet, and similar areas. First, effective rodent control measures should be implemented in both urban and agricultural areas, including targeted rodent trapping, improved environmental sanitation, and better waste management, to reduce the rat population, which serves as a significant reservoir for *Leptospira*. Additionally, improving flood control infrastructure and drainage systems is crucial, as the low-lying terrain and flooding in the study area may contribute to the persistence of leptospires in the environment. This can help minimize standing water, a key habitat for the survival of *Leptospira*, and reduce the risk of environmental contamination.

Community awareness and education are also critical. Local public health campaigns should focus on educating people, particularly those working in agriculture and areas with high rat populations, about the risks of leptospirosis and preventive measures, such as using protective gear, properly disposing of waste, and avoiding contact with potentially contaminated water sources. Regular surveillance of rodent populations is also recommended to monitor the spread of leptospirosis and identify areas of higher risk. Rapid diagnostic methods such as LAMP can be used for ongoing monitoring to guide public health responses more effectively.

Given the potential for leptospirosis transmission to livestock and domestic animals, veterinary monitoring and health programs should be strengthened. Livestock owners should be educated about the risks of leptospirosis and encouraged to adopt preventive measures to protect both animals and humans. Furthermore, continued molecular surveillance is essential to explore the full range of *Leptospira* serovars circulating in the area, providing valuable information for targeted diagnostic and control strategies. Sequencing additional positive samples will deepen our understanding of the strains in circulation and help inform future public health interventions.

In addition, future research should consider including variables such as the species, age, and sex of rats, as these factors have been shown to influence the likelihood of *Leptospira* carriage (Ivanova *et al*., 2012; Levett, 2001). Incorporating these variables would provide more detailed insights into the epidemiology of leptospirosis and improve understanding of how the disease is transmitted in urban and agricultural environments. Furthermore, studies with larger sample sizes, including both humans and other animals, would be beneficial to determine the full transmission cycle of leptospirosis and assess the status of this zoonosis.

Lastly, a One Health approach that integrates human, animal, and environmental health sectors should be adopted. This approach would facilitate collaboration between local health authorities, agricultural departments, environmental agencies, and the community, ensuring a coordinated response to leptospirosis and enhancing overall public health management. By addressing these recommendations, local authorities can better manage and reduce the risk of leptospirosis in both human and animal populations, ultimately improving public health in La Trinidad and surrounding areas.

REFERENCES

[1] P. N. Acha and B. Szyfres, *Zoonoses and Communicable Diseases Common to Man and Animals*, 3rd ed., vol. 1. Washington, D.C.: Pan American Health Organization, 2003, pp. 157–168.

[2] J. Adler and M. A. de la Peña Moctezuma, "Leptospira and leptospirosis," *Vet. Microbiol.*, vol. 140, no. 3–4, pp. 287–296, 2009.

[3] M. Bonilla-Santiago and J. E. Nally, "Rat model of chronic infection for pathogenic Leptospira interrogans serovar Copenhageni," *Infect. Immun.*, vol. 79, no. 2, pp. 193–199, 2011.

[4] R. Dhama *et al*., "Loop-mediated isothermal amplification of DNA (LAMP): A new diagnostic tool lights the world of diagnosis of animal and human pathogens: A review," *Pak. J. Biol. Sci.*, vol. 17, no. 2, pp. 151–166, 2014.

[5] P. Francois *et al*., "Robustness of a loop-mediated isothermal amplification reaction for diagnostic applications," *FEMS Immunol. Med. Microbiol.*, vol. 62, no. 1, pp. 41–48, 2011.

[6] M. Guerra, "Leptospirosis: Public health perspectives," *Curr. Top. Microbiol. Immunol.*, vol. 387, pp. 1–22, 2009.

[7] H. Ivanova *et al*., "Factors associated with the prevalence of Leptospira in small mammals in lowland and upland agricultural communities," *Epidemiol. Infect.*, vol. 140, no. 5, pp. 820–830, 2012.

[8] H. Kaneko *et al*., "Tolerance of loop-mediated isothermal amplification to a culture medium and biological substances," *J. Biochem. Biophys. Methods*, vol. 70, no. 3, pp. 499–501, 2007.

[9] N. Koizumi *et al*., "Detection of Leptospira DNA by loop-mediated isothermal amplification," *J. Clin. Microbiol.*, vol. 50, no. 4, pp. 1224–1227, 2012.

[10] N. Koizumi, Y. Muto, K. Tanikawa, Y. Mizutani, and H. Takada, "Molecular typing of Leptospira interrogans in rats for assessment of the source of human infection in Osaka City, Japan," *J. Med. Microbiol.*, vol. 58, no. 6, pp. 681–685, 2009.

[11] D. Levett, "Leptospirosis," *Clin. Microbiol. Rev.*, vol. 14, no. 2, pp. 296–326, 2001.

[12] J. Thiermann, "Experimental leptospiral infections in pregnant and nonpregnant cattle with organisms of serogroup Pomona," *Am. J. Vet. Res.*, vol. 42, pp. 1133–1136, 1981.

[13] J. Wasiński and A. M. Dutkiewicz, "Leptospirosis—Current risk factors connected with human activity and the environment," *Ann. Agric. Environ. Med.*, vol. 20, no. 2, pp. 239–244, 2013.

[14] J. M. Srikram, S. Zhang, T. Sugunan, and C. A. Smythe, "Use of LAMP for rapid detection of Leptospira from clinical samples," *Ann. Trop. Med. Parasitol.*, vol. 102, no. 2, pp. 121–127, 2008.

[15] G. E. Torres, J. A. Amagan, and J. M. Tamayo, "Prevalence and risk factors of leptospirosis among rice farmers in Southern Philippines," *Acta Med. Philipp.*, vol. 50, no. 3, pp. 215–220, 2016.

[16] M. G. World Health Organization, "Human leptospirosis: Guidance for diagnosis, surveillance and control," WHO, Geneva, 2003. [Online]. Available: https://www.who.int/publications/i/item/human-leptospirosis-guidance-for-diagnosis-surveillance-and-control

[17] World Health Organization, "Leptospirosis burden epidemiology reference group (LERG)," WHO, Geneva, 2010. [Online]. Available: https://www.who.int/zoonoses/diseases/lerg/en/

[18] A. Ko *et al*., "Urban epidemic of severe leptospirosis in Brazil," *Lancet*, vol. 354, pp. 820–825, 1999.

[19] S. Koizumi and S. I. Watanabe, "Leptospirosis vaccines," *Vaccine*, vol. 20, pp. 2021–2023, 2002.

[20] C. K. Lindow *et al*., "Use of polymerase chain reaction and loop-mediated isothermal amplification assays for diagnosis of leptospirosis in rats in the Philippines," *Trop. Biomed.*, vol. 33, no. 2, pp. 239–248, 2016.

[21] A. A. Limmathurotsakul *et al*., "Epidemiology and burden of leptospirosis in Thailand: a systematic review," *PLoS Negl. Trop. Dis.*, vol. 8, no. 11, p. e3330, 2014.

[22] M. Lucero *et al*., "Leptospirosis in children in the Philippines: An overlooked public health problem," *Southeast Asian J. Trop. Med. Public Health*, vol. 25, no. 2, pp. 398–402, 1994.

[23] M. M. Marquez *et al*., "Human leptospirosis and rainfall in the Philippines," *Asia Pac. J. Public Health*, vol. 29, no. 2, pp. 91–99, 2017.

[24] R. M. McBride, C. R. Athanazio, S. A. Reis, and A. I. Ko, "Leptospirosis," *Curr. Opin. Infect. Dis.*, vol. 18, pp. 376–386, 2005.

[25] H. A. Miller *et al*., "Use of multiple laboratory tests for diagnosis of leptospirosis in the Philippines," *Am. J. Trop. Med. Hyg.*, vol. 89, no. 6, pp. 1230–1232, 2013.

Estimation of Heritability, Genetic Advance and Correlation for Quantitative Traits in M3-Generation Chickpea (*Cicer arietinum* L.) under Induced EMS Mutagenesis

Waseem Uddin MD[1]; Swathi Bai M[2]; G.Vijay Kumar[3]; K. Srinivas Naik[4*]
[1,4]Centre for Plant Molecular Biology, Osmania University, Hyderabad-07
[2,3]Department of Genetics & Biotechnology, Osmania University, Hyderabad-07
*Corresponding Author

Received:- 08 April 2025/ Revised:- 14 April 2025/ Accepted:- 25 April 2025/ Published: 30-04-2025

Abstract**—** *An experiment was carried out with two varieties of chickpea-IC265291 (V1) and IC265298 (V2) which were obtained from NBPGR, New Delhi to study the Heritability, correlation and Genetic advance as percent of the mean for 11 quantitative characters. Healthy & Uniform seeds of two varieties of chickpea were treated with different concentrations of chemical mutagen EMS (Ethyl Methyl Sulfonate) viz:0.1%, 0.2%, 0.3%, 0.4%, 0.5% and 0.6%.The seeds were grown in petri plates and seed survival rate and seedling characters were studied. The EMS-treated seeds along with the control (untreated) seeds were sown in the field at CPMB (Centre for Plant Molecular Biology), Osmania University, Hyderabad. The result of the study, revealed that all the characters under study were shown significant phenotypic and genotypic correlations with seed weight except days to flower initiation, days to 50% flowering and days to pod maturity. In Chickpea, Phenotypic Coefficient of Variation (PCV) for all the traits is found to be higher than Genotypic Coefficient of Variation (GCV).For the traits Number of branches per plant, Number of pods per plant, Pod weight per plant, Number of seeds per plant and 100 seed weight-Heritability(h^2) and Genetic Advance(GA) are found to be higher. These are the most important traits that can be utilised for the improvement of seed yield in chickpea.*

Keywords**— Chickpea, Heritability, Genetic Advance, Correlation, Induced EMS.**

I. INTRODUCTION

The chickpea, known scientifically as *Cicer arietinum*, is an annual legume in the *Fabaceae* family cultivated for its edible seeds. This plant features a branched stem that can be straight or slightly bent, adorned with small feathery leaves that grow alternately along the stem. Chickpea are an abundant and affordable source of protein, which can aid individuals in enhancing the nutritional value of their diets, thereby playing an important role in food security in developing nations.(Kumar et al., 1900).It offers significant benefits for individuals with diabetes and provides a rich supply of essential nutrients including vitamins A, C, E, K, B1–B3, B5, B6, B9, as well as minerals like iron, zinc, magnesium, and calcium, all of which contribute positively to human health.(Koul et al., 2022).Chickpeas are a significant legume cultivated across approximately 18 million hectares globally, serving as an essential dietary source for many people in semiarid tropical regions and contributing greatly to the sustainable productivity of farming systems (Vadez et al., 2021). Chickpeas (*Cicer arietinum* L.) are a significant pulse crop cultivated and eaten globally, particularly in countries across Africa and Asia. They provide a substantial amount of carbohydrates and protein, with the quality of protein being regarded as superior to that of other pulses (Jukanti et al., 2012). Chickpea (*Cicer arietinum* L.), which includes both desi and kabuli types, is a cherished pulse crop around the world. Its cultivation takes place in more than fifty countries, ranging from the Indian subcontinent and southern Europe to the Middle East, North Africa, the Americas, Australia, and China. Comprising 80% of its dry seed mass, chickpea is rich in carbohydrates and protein, and it is recognized for its various health advantages, earning it the designation of a 'functional food' (Zhang et al., 2024). Mutation breeding serves as a valuable method for generating genetic diversity in chickpea cultivation, given its self-pollinating characteristics and limited genetic diversity (Dinkar et al., 2020). Ethyl methane sulfonate (EMS) mutagenesis serves as an effective method for creating genetic resources that help uncover underexplored genes and analyse gene functions to gain insights into the molecular foundation of significant agronomic traits (Chen et al., 2022). Both physical and chemical agents can be utilized to generate mutations in advanced plant species. Among the physical agents, gamma rays are favored in higher plants because of their ability to penetrate deeply, while among the chemical agents, ethyl methane sulphonate (EMS) is chosen for its capability to cause a high frequency of mutations that are irreversible (Journal et al., 2019). Chemical mutagenesis offers a cost-effective, straightforward, and convenient method for generating allelic variation in the genomes of plants and animals. Various chemical mutagens induce distinct forms of DNA damage, including alkylating agents and azides (Subramaniam & Kumar, 2023). The genetic improvement of any crop largely relies on the genetic diversity available within the population, while germplasm acts as an important reservoir of base population and offers a source of extensive variability (Shedge et al., 2019). Any breeding program's ability to succeed is largely dependent on the population's genetic diversity (Ene et al., 2016). Heritability examines the connection between genotypic variance and the underlying true genotypic values of observed and phenotypic variance (Turk, n.d.). The level of gain achieved in a character under a specific selection pressure is explained by genetic advancement. High estimates of heritability combined with high genetic advancement provide the ideal environment for selection. Additionally, it shows that the trait contains additive genes, which further suggests that selecting for such qualities will result in dependable crop development (Mofokeng et al., 2019). The term "heritability" refers to the degree to which genetic variation accounts for a trait's variation. (Estimating Trait Heritability Learn Science at Scitable, n.d.). Genetic advance and heritability aid in assessing how the environment affects character expression and how much improvement is feasible following selection (Sriraj & Gurjar, 2022).

II. MATERIALS & METHODS

Two chickpea genotypes IC265291 (V1) and IC265298 (V2) were collected from NBPGR, New Delhi. These seeds were soaked in distilled water and they were treated with different concentrations of EMS (mutagen) viz; 0.1%, 0.2%, 0.3%, 0.4%, 0.5%, 0.6% and excess of the EMS is removed by thorough washing the seeds with distilled water. Seeds were kept in triplicate in petriplates for germination study. On the 5th day, seed germination was observed with the emergence of cotyledon leaf. Germination percentage and Seed survival was worked out for each accession separately. The treated seeds and untreated (Control) forms the M0-Generation which were sown in the pots in CRBD pattern. In each row of 10m length, 10 plants were maintained with 10cm space between them. In between 2 rows, 30cm space was maintained. The observations were recorded on Height of the plant (cm), Number of Branches (per plant), Days for Initial Flowering, Days for 50% Flowering, Days for Pod Maturity, Number of Pods per Plant, Pod weight per Plant, Number of Seeds per Pod, Number of Seeds per Plant, Seed Weight (in gm per plant) and 100 Seeds weight (in gm).The mutagenized first generation-M1 plants were self-pollinated to raise M2-generation.In M2-genetaion the high seed yield plants were harvested separately and their seeds were sown in the field to raise M3-generation.In M3-generation Seed Yield and Yield contributing characters were recorded. In accordance with Panse and Sukhatme (1967), the statistical analysis and variance resulting from various sources were calculated. Genotypic Coefficient of Variation & Phenotypic coefficient of variation were computed using Burton's (1952) recommended methodology. Broad Sense Heritability & Genetic Advance as percentage of means were estimated as suggested by Jhonson et al. (1955).

III. RESULTS AND DISCUSSION

TABLE 1
PHENOTYPIC CORRELATION FOR QUANTITATIVE TRAITS WITH SEED YIELD IN CHICKPEA IN M3 GENERATION UNDER EMS INDUCED MUTAGENESIS

No.	Character	1	2	3	4	5	6	7	8	9	10	11
		Pl. Ht	P.Br/pl	Days to F. Ini	Days to 50% F	Days to P.M	No. of P/pl	Pod. Wt (g/pl)	No. of S/Pod	No. of S/pl	100 S. wt (g/pl)	S. wt (g/pl)
1	Pl. Ht	1.000	0.965**	-0.925**	-0.916**	-0.885**	0.562**	0.957**	0.953**	0.963**	0.958**	0.906**
2	P.Br/pl		1.000	-0.900**	-0.900**	-0.850**	0.933**	0.916**	0.935**	0.943**	0.937**	0.885**
3	Days to F. Ini			1.000	0.990**	0.978**	-0.978**	-0.965**	-0.945**	-0.976**	-0.978**	-0.957**
4	Days to 50% F				1.000	0.980**	-0.970**	-0.952**	-0.946**	-0.973**	-0.976**	-0.961**
5	Days to P.M					1.000	-0.963**	-0.963**	-0.919**	-0.956**	-0.949**	-0.944**
6	No. of P/pl						1.000	0.991**	0.960**	0.986**	0.981**	0.953**
7	Pod. Wt (g/pl)							1.000	0.937**	0.969**	0.960**	0.938**
8	No. of S/Pod								1.000	0.982**	0.954**	0.934**
9	No. of S/pl									1.000	0.995**	0.971**
10	100 S. wt (g/pl)										1.000	0.972**

Pl.ht- Plant height (cm); Br/pl- Number of branches per plant; Days F.Ini- Days to flower initiation; Days 50% F- days to 50% of flowering; Days to P.M.-Days to pod maturity; No.of P/Pl- Number of pods per plant; Pod.Wt/Pl(g)- pod weight per plant (g); No.of S/pl-Number of seeds per plant; Seed.Wt (g/Pl)- seed weight per plant (g); 100 S.wt(g)- 100 seed weight (g).

In M3-generation, the phenotypic correlation analysis revealed that the trait correlated significantly for seed weight per plant (in gm) with plant height (in cm) 0.906**, Number of branches (per plant) 0.885**, Number of pods (per plant) 0.953**, pod weight (in gm per plant) 0.935**, Number of seeds (per plant) 0.954**, 100 seed weight (in gm per plant) 0.972** and negatively phenotypically correlated with the traits number of days for initial flowering -0.957**, number of days for 50% flowering -0.961**, number of days taken for pod maturity -0.954**.The trait 100 seed weight (in gm per plant), phenotypically correlated positively with the traits plant height (in cm) 0.955**, number of branches (per plant) 0.937**, number of pods (per plant) 0.981**, pod weight (in gm per plant) 0.960**, number of seeds (per pod)0.984**, number of seeds (per plant) 0.995**and negatively phenotypically correlated with the traits number of days for initial flowering -0.978**, number of days for 50% flowering -0.975**, number of days taken for pod maturity -0.949**.The trait number of seeds per plant correlated positively for the traits plant height (in cm) 0.963**, Number of branches (per plant) 0.945**, Number of pods (per plant) 0.986**, pod weight (in gm per plant) 0.969**, Number of seeds (per pod) 0.982** and negatively phenotypically correlated with the traits number of days for initial flowering -0.976**, number of days for 50% flowering -0.975**, number of days taken for pod maturity -0.956**.The quantitative character number of seeds per pod positively correlated with plant height (in cm) 0.953**, number of branches per plant 0.935**, number of pod (per plant) 0.960**, pod weight (in gm per plant) 0.937** but negatively correlated with the traits number of days for initial flowering -0.945, number of days for 50% flowering -0.946**, number of days taken for pod maturity -0.915**.The phenotypic character Pod weight (in gm per plant) correlated positively with plant height (in gm) 0.957**, number of branches (per plant) 0.916**, number of pods (per plant) 0.991** and negatively correlated with the traits number of days for initial flowering -0.965**, number of days for 50% flowering -0.952**, number of days taken for pod maturity -0.963.The character number of pods (per plant) is positively correlated with the traits plant height (in cm) 0.962** and number of branches (per plant) 0.939** but negatively correlated with the number of days for initial flowering -0.978**, number of days for 50% flowering -0.970**, number of days taken for pod maturity -0.963**.The trait number of days taken for pod maturity is positively correlated with the traits the number of days (taken for initial flowering) 0.978** , number of days taken for 50% flowering 0.980** but negatively correlated with the trait plant height (in cm) -0.885** and the trait number of branches (per plant) -0.850**.The quantitative character number of days taken for 50% flowering is positively correlated with number of days taken for initial flowering 0.990**and it is negatively correlated with plant height (in cm) -0.916** and number of branches per plant -0.900**.The trait number of days for flower initiation is correlated negatively with the trait plant height (in cm) and number of branches (per plant) -0.925** and -0.900** respectively. The trait number of branches per plant is positively correlated with the trait plant height (in cm) 0.965**.

TABLE 2
GENOTYPIC CORRELATION FOR QUANTITATIVE TRAITS WITH SEED YIELD IN CHICKPEA IN M3 GENERATION UNDER EMS INDUCED MUTAGENESIS

No.	Character	1 (Pl. Ht)	2 (P.Br/pl)	3 (Days to F. Ini)	4 (Days to 50% F)	5 (Days to P.M)	6 (No. of P/pl)	7 (Pod. Wt)	8 (No. of S/Pod)	9 (No. of S/pl)	10 (100 S. wt)	11 (S. wt)
1	Pl. Ht	1.000	0.968**	-0.928**	-0.917**	-0.858**	0.963**	0.958**	0.972**	0.968**	0.961**	0.937**
2	P.Br/pl		1.000	-0.905**	-0.904**	-0.855**	0.943**	0.919**	0.961**	0.955**	0.946**	0.924**
3	Days to F. Ini			1.000	0.991**	0.981**	-0.958**	-0.970**	-0.970**	-0.964**	-0.968**	-0.995**
4	Days to 50% F				1.000	0.983**	-0.972**	-0.954**	-0.970**	-0.958**	-0.928**	-0.979**
5	Days to P.M					1.000	-0.965**	-0.963**	-0.935**	-0.961**	-0.955**	-0.985**
6	No. of P/pl						1.000	0.991**	0.981**	0.991**	0.983**	0.968**
7	Pod. Wt (g/pl)							1.000	0.960**	0.975**	0.966**	0.966**
8	No. of S/Pod								1.000	0.994**	0.997**	0.984**
9	No. of S/pl									1.000	0.997**	0.990**
10	100 S. wt (g/pl)										1.000	0.997**

Pl.ht- Plant height (cm); Br/pl- Number of branches per plant; Days F.Ini- Days to flower initiation; Days 50% F- days to 50% of flowering; Days to P.M.-Days to pod maturity; No.of P/Pl- Number of pods per plant; Pod.Wt/Pl(g)- pod weight per plant (g); No.of S/pl-Number of seeds per plant; Seed.Wt (g/Pl)- seed weight per plant (g); 100 S.wt(g)- 100 seed weight (g).

In M3-generation, the genotypic correlation data analysis revealed that the trait seed weight per plant was highly significant genotypically correlation with plant height (cm) 0.937**, number of branches per plant 0.924**, number of pods per plant 0.986**, pod weight per plant 0.966**, number of seeds per pod 0.984**, number of seeds per plant 0.997**, 100 seed weight per plant 0.997** but it was observed that the seed weight recorded highly negative genotypically correlated with days to flower initiation -0.995**, days to 50% flowering -0.997**, days to pod maturity-0.985**.It also revealed that the trait plant height was highly significant genotypically correlation with branches per plant 0.968**, number of pods per plant 0.963**, pod weight per plant 0.958**, number of seeds per pod 0.972**, number of seeds per plant 0.968**, 100 seed weight per plant 0.961**, seed weight per plant 0.937**, but it was observed that plant height was highly negative genotypically correlated with days to flower initiation -0.928**, days to 50% flowering -0.917**, days to P.M -0.888**.The trait number of branches per plant was highly significant genotypically correlation with number of pods per plant 0.943**, pod weight per plant 0.919**, number of seeds per pod 0.961**, number of seeds per plant 0.955**, 100 seed weight per plant 0.946**, seed weight per plant 0.924**, but it was observed that number of branches per plant days to flower initiation -0.905**, days to 50% flowering -0.904**, days to P.M -0.855**.The trait number of days to flower initiation was highly significant genotypically correlation with days to 50% flowering 0.991**, days to P.M 0.981**, but it was observed that days to flower initiation was highly negative genotypically correlated with number of pods per plant -0.982**, pod weight per plant -0.970**, number of seeds per pod -0.970**, number of seeds per plant -0.984**, 100 seed weight per plant -0.986**, seed weight per plant (g) -0.995**.The statistical analysis results revealed that the trait days to 50% flowering was highly significant genotypically correlation with days to pod maturity 0.983**, but it was observed that days to 50% flowering was highly negative genotypically correlated with number of pods per plant -0.972**, pod weight per plant -0.954**, number of seeds per pod -0.970**, number of seeds per plant -0.982**, 100 seed weight per plant -0.982**, seed weight per plant (g) -0.997**.The trait number of days taken to pod maturity was highly negative genotypically correlated with number of pods per plant -0.965**, pod weight per plant -0.965**, number of seeds per pod -0.935**, number of seeds per plant -0.961**, 100 seed weight per plant -0.955**, seed weight per plant (g) -0.985**.The trait number of pods per plant was highly significant genotypically correlation with pod weight per plant 0.991**, number of seeds per pod 0.981**, number of seeds per plant 0.991**, 100 seed weight per plant 0.987**, seed weight per plant (g) 0.986**. The trait pod weight per plant was highly significant genotypically correlation with number of seeds per pod 0.960**, number of seeds per plant 0.975**, 100 seed weight per plant 0.966**, seed weight per plant (g) 0.966**.The trait number of seeds per pod was highly significant genotypically correlation with number of seeds per plant 0.994**, 100 seed weight per plant 0.997**, seed weight per plant (g) 0.984**.The trait number of seeds per plant was highly significant genotypically correlation with 100 seed weight per plant 0.997**, seed weight per plant (g) 0.997**.The correlation statistical analysis results revealed that the trait 100 seed weight per plant (g) was highly significant genotypically correlation with seed weight per plant (g) 0.997**, in our study.

TABLE 3
ESTIMATION OF HERITABILITY, GCV AND PCV, GENETIC ADVANCE AND GENETIC ADVANCE VALUE % MEANS

S.No	Characters	Heritability (%)	Genotypic Coefficient of Variations	Phenotypic Coefficient of Variations	Genetic Advance	Genetic Advance value % means
1	**Pl. Ht**	99.677	18.584	18.615	12.209	38.219
2	**P.Br/pl**	99.104	28.634	28.763	5.927	58.721
3	**Days. F.Ini**	99.398	12.012	12.049	9.229	24.671
4	**Days to 50% F**	99.616	12.413	12.436	10.560	25.521
5	**Days to P.M**	99.793	6.450	6.457	11.520	13.274
6	**No.of P/pl**	99.823	39.283	39.318	26.260	80.851
7	**Pod.Wt/pl(g)**	99.804	40.235	40.275	14.654	82.803
8	**No.of S/Pod**	95.543	19.238	19.681	0.572	38.737
9	**No.of S/pl**	99.162	49.657	49.866	50.156	101.863
10	**100 S. wt(g)**	98.961	49.580	49.839	12.184	101.603
11	**S. wt(g/pl)**	93.579	16.948	17.520	6.762	33.774

Pl.ht- Plant height (cm); Br/pl- Number of branches per plant; Days F.Ini- Days to flower initiation; Days 50% F- days to 50% of flowering; Days to P.M.-Days to pod maturity; No.of P/Pl- Number of pods per plant; Pod.Wt/Pl(g)- pod weight per plant (g); No.of S/pl-Number of seeds per plant; Seed.Wt (g/Pl)- seed weight per plant (g); 100 S.wt(g)- 100 seed weight (g).

3.1 Estimation of Heritability, GCV and PCV, Genetic advance and Genetic advance value % Means:

In M3-Generation, the Phenotypic Coefficient of Variation (PCV) recorded for the character plant height is 18.615, and the Genotypic Coefficient of Variation observed is 18.548.Heritability estimation recorded is 99.677 and Genetic Progress is 38.219 percent above the norm. The PCV recorded for number of branches per plant is 28.763 and the GCV was observed as 28.634.Heritability is observed as 99.104 and genetic progress as 58.721.The PCV and GCV values for number of days for flower initiation is 12.049 and 12.012 respectively. The observed genetic progress as a percent of mean is 24.671 percent and the heritability estimation is 99.398.The observed PCV value is 12.436 and the GCV is 12.413.Heritability estimates is found to be 99.616 and genetic advance is 25.521 percent of the mean. The PCV and GCV for the trait number of days for pod maturity is 6.457 and 6.540 respectively. Heritability estimates is 99.793 and genetic progress value is 13.274 percent of the mean. The phenotypic coefficient of variation for the trait number of pods per plant is 39.318 and the genotypic coefficient of variation is 39.283.The genetic improvement as a percent of mean is 80.851 and the heritability is 99.823.For the trait pod weight per plant, the phenotypic coefficient of variation and genotypic coefficient of variation values are 40.275 and 40.235 respectively. Heritability is observed as 99.804 and genetic progress as 82.803 percent above the norm. The PCV and GCV values for the trait number of seeds per pod is 19.681 and 19.238 respectively. Heritability estimations is found to be 95.543 and genetic progress is found to be 38.737 percent of the mean. The phenotypic coefficient of variation (PCV) value observed for the character number of seeds per plant is 649.866 and the genotypic coefficient of variation (GCV) is 49.657.Heritability estimation value is 99.162 and the genetic progress observed is 101.863 percent of the mean. The phenotypic coefficient of variation observed for the trait 100 seed weight per plant is 49.839 and the genotypic coefficient of variation observed is 49.580.The observed genetic progress as the percent of the mean is 101.603 and the heritability estimates are 98.961.The phenotypic coefficient of variation and the genotypic coefficient of variation recorded is 17.520 and 16.948 respectively. Genetic progress is 33.774 percent above the norm and the heritability estimation is 93.579.

TABLE 4
PHENOTYPIC AND GENOTYPIC CORRELATION OF THE TRAITS WITH SEED YIELD IN M3 GENERATION

	Phenotypic Correlation	Genotypic Correlation
Traits	**Seed weight/pl**	
Pl. Ht	0.906**	0.937**
P.Br/pl	0.885**	0.924**
Days to F.Ini	-0.957**	-0.995**
Days to 50% F.	-0.961**	-0.997**
Days to P.M.	-0.954**	-0.985**
No.of P/pl	0.953**	0.986**
Pod.Wt (g/pl)	0.935**	0.966**
No.of S/Pod	0.954**	0.984**
No.of S/pl	0.971**	0.997**
100 S. wt (g/pl)	0.972**	0.997**

Pl.ht- Plant height (cm); Br/pl- Number of branches per plant; Days F.Ini- Days to flower initiation; Days 50% F- days to 50% of flowering; Days to P.M.-Days to pod maturity; No.of P/Pl- Number of pods per plant; Pod.Wt/Pl(g)- pod weight per plant (g); No.of S/pl-Number of seeds per plant; Seed.Wt (g/Pl)- seed weight per plant (g); 100 S.wt(g)- 100 seed weight (g).

The correlation analysis results revealed that all the traits except Days to initiation of flowering, Days to 50% flowering and Days to pod maturity were shown significant phenotypic and genotypic possitive correlations with seed weight. The most yield contributing traits such as pods per plant, seeds per plant and 100 seed weight showed significant positive correlation with seed yield in blackgram earlier by Bhattu et al., 2023.

TABLE 5
ESTIMATION OF HERITABILITY, GCV AND PCV, GENETIC ADVANCE AND GENETIC ADVANCE VALUE % MEANS

S.No	Characters	Heritability (%)	Genotypic Coefficient of Variations	Phenotypic Coefficient of Variations	Genetic Advance	Genetic Advance value % means
1	**No.of P/pl**	99.823	39.283	39.318	26.26	80.851
2	**Pod.Wt/pl(g)**	99.804	40.235	40.275	14.654	82.803
3	**No.of S/pl**	99.162	49.657	49.866	50.156	101.863
4	**100 S. wt(g)**	98.961	49.58	49.839	12.184	101.603

No.of P/Pl- Number of pods per plant; Pod.Wt/Pl(g)- pod weight per plant (g); No.of S/pl-Number of seeds per plant; 100 S.wt(g)- 100 seed weight (g).

In our study, the heritability and genetic advance (GA) was found higher for majority of the characters. It can be concluded that number of pods per plant, number of seeds per plant, pod weight, seed weight and 100 seed weights are most important traits in chickpea which can be used for the improvement of seed yield. Phenotypic coefficients of variation (PCV) is little higher than the genotypic coefficients of variation (GCV) for all the traits under study in chickpea mutant. It reveals that no environmental effect or very little environmental influence on selected characters in our mutants (Table). Similar results were found with work of Bhattu et al., 2023 in blackgram.

IV. CONCLUSION

All the traits except Days to initiation of flowering, Days to 50% flowering and Days to pod maturity were shown significant phenotypic and genotypic correlations with seed weight. Phenotypic coefficients of variation (PCV) is higher than the genotypic coefficients of variation (GCV) for all the traits under study in chickpea mutant. Heritability and Genetic Advance (GA) was found higher for majority of the characters. It can be concluded that number of pods per plant, number of seeds per plant, pod weight, seed weight and 100 seed weights are most important traits in chickpea which can be used for the improvement of seed yield.

ACKNOWLEDGEMENT

This is a part of my Ph.D work and I am extremely grateful to Department of Genetics & Biotechnology, Osmania University, Hyderabad for providing the field and laboratory facilities for conducting experiments. I also acknowledge NBPGR, New Delhi for providing seed material of chickpea genotypes.

REFERENCES

[1] Bhattu Rajesh Nayak, K Srinivas Naik, Raju Padiya, G Kumara Joshi and G. Vijay Kumar.2023. Studies on Correlation, Genetic Advance and Heritability for Seed Yield and its Contributing Traits of EMS Induced Blackgram (Vigna mungo L Hepper) Mutants in M3 Generation. Research & Reviews: Journal of Agriculture and Allied Sciences, 12(1): 1-7.

[2] L. Chen, Duan, L., Sun, M., Yang, Z., Li, H., Hu, K., Yang, H., & Liu, L. (2022). Current trends and insights on EMS mutagenesis application to studies on plant abiotic stress tolerance and development. Frontiers in Plant Science, 13. https://doi.org/10.3389/FPLS.2022.1052569.

[3] V. Dinkar, Arora, A., Panwar, R., & Verma, S. (2020). Mutagenesis induced variability through gamma rays, EMS and combination treatments in chickpea genotypes. ~ 1139 ~ Journal of Pharmacognosy and Phytochemistry, 9(2). www.phytojournal.com.

[4] C. Ene, O. Ogbonna, P. E., Agbo, C. U., & Chukwudi, U. P. (2016). Studies of phenotypic and genotypic variation in sixteen cucumber genotypes. Chilean Journal of Agricultural Research, 76(3), 307–313. https://doi.org/10.4067/S0718-58392016000300007.

[5] Journal, Sharma I., N., Katna, G., Joshi Saha, A., & Dev Sharma, K. (2019). Generation of Variability in Chickpea (Cicer arietinum L.) through Mutagenesis Generation of Variability in Chickpea through Mutagenesis.Ecology, 46(3).

[6] A. K. Jukanti, Gaur, P. M., Gowda, C. L. L., & Chibbar, R. N. (2012). Nutritional quality and health benefits of chickpea (Cicer arietinum L.): a review. The British Journal of Nutrition, 108 Suppl 1(SUPPL. 1). https://doi.org/10.1017/S0007114512000797.

[7] B. Koul, Sharma, K., Sehgal, V., Yadav, D., Mishra, M., & Bharadwaj, C. (2022). Chickpea (*Cicer arietinum* L.) Biology and Biotechnology: From Domestication to Biofortification and Biopharming. Plants, 11(21), 2926. https://doi.org/10.3390/PLANTS11212926.

[8] S. Kumar, Katna, G., & Sharma, N. (2019). Mutation breeding in chickpea. Advances in Plants and Agriculture Research. 2019; 9(2):355–362. https://doi.org/10.15406/apar.2019.09.00448.

[9] M. A. Mofokeng, Shimelis, H., Laing, M., & Shargie, N. (2019). Genetic variability, heritability and genetic gain for quantitative traits in South African sorghum genotypes. Australian Journal of Crop Science, 13(1), 1–10. https://doi.org/10.21475/ajcs.19.13.01.p718.

[10] P. J. Shedge, Patil, D. K., & Misal, M. R. (2019). Assessment of Genetic Variability in Chickpea (Cicer arietinum L.). International Journal of Current .Microbiology and Applied Science, 8(7), 1339–1344. https://doi.org/10.20546/ijcmas.2019.807.159.

[11] P. Sriraj, & Gurjar, D. (2022). Studies of Genetic Variability, Heritability and Genetic Advance in Yield Component Traits in Chickpea (*Cicer arietinum* L.). International Journal of Environment and Climate Change, 1805–1810. https://doi.org/10.9734/IJECC/2022/V12I1131166.

[12] R. Subramaniam, & Kumar, V. S. (2023). Ethyl Methanesulphonate (EMS)-Mediated Mutagenesis Induces Genetic and Morphological Variations in Eggplant (Solanum melongena L.). International Journal of Plant Biology, 14(3), 714–728. https://doi.org/10.3390/IJPB14030053/S1.

[13] Z. Turk, (n.d.). Estimate of quantitative heritability in some chickpea genotypes (*Cicer arietinum* L.). https://cabidigitallibrary.org.

[14] V. Vadez, Hajjarpoor, A., Korbu, L. B., Alimagham, M., Pushpavalli, R., Ramirez, M. L., Kashiwagi, J., Kholova, J., Turner, N. C., & Sadras, V. O. (2021). Chickpea. Crop Physiology Case Histories for Major Crops, 342–358. https://doi.org/10.1016/B978-0-12-819194-1.00010-4.

[15] J. Zhang, Wang, J., Zhu, C., Singh, R. P., & Chen, W. (2024). Chickpea: Its Origin, Distribution, Nutrition, Benefits, Breeding, and Symbiotic Relationship with Mesorhizobium Species. Plants 2024, Vol. 13, Page 429, 13(3), 429. https://doi.org/10.3390/PLANTS13030429.

SPIONs Weapons by Moringa Oleifera finally improves outcome of Multi-Organ Damages (MODs) Prevention: Fact or hype for Reason behind Fighting High Sepsis Rates

Peni K. Samsuria Mutalib[1], Indranila Kustarini Samsuria[2], Arindra Adi Rahardja[3]

[1]Medical Physics Department Faculty of Medicine, University of Indonesia-RSCM Teaching Hospital, JAKARTA 10430.
[2]Clinical Pathology Department Ret Faculty of Medicine, Universitas Diponegoro-RSDK Teaching Hospital, SEMARANG, Central Java 50244
[2]Central Laboratory, Faculty of Medicine University of Diponegaro-Dr. Kariadi Central General Hospital, SEMARANG, Central Java 50244
[3]Puskesmas Tlogosari Kulon, SEMARANG, Central Java 50196, Indonesia
*Corresponding Author

Received:- 08 April 2025/ Revised:- 17 April 2025/ Accepted:- 22 April 2025/ Published: 30-04-2025

***Abstract*—**

Introduction: *Spinel ferrite nanoparticles (Superparamagnetic Iron Oxide Nanoparticles/SPIONs) semiconductors have been broadly reported to kill bacteria outside the human body. SPIONs as photocatalytic agents in coloring dye water treatment have different mechanisms, it's a redox reaction. SPIONs as MRI agents have the same principle as bacteria killer, to emit electromagnetic waves. Winning against the high prevalence of MODs and sepsis is the aim of this study.*

Method: *Review article of Ex/Em SPIONs semiconductor in Photothermal Therapy (PTT).*

Result: *Table of 16 references which support SPIONs as New Generation (NG) antibiotic to kill resistant bacteria inside the body.*

Discussion: *Moringa oleifera gold composite NPs vs. NG beta-lactams. SPIONs green synthesis gold composite NPs are used as photothermal therapy (PTT) based on inducing hyperthermia to kill bacteria inside the body: NG MDR eradication.*

Conclusion: *PTT therapy achieved with SPIONs, under NIR, is used to kill MDR, XDR, TDR micro-bacteria, fungi and cancer cells inside the human body.*

***Keywords*— Splenectomy, Moringa oleifera, Ferrite NPs, Antimicrobia resistant, Inside the body, PTT.**

I. INTRODUCTION

Multi organ damages (MODs) is the terminal cases of sepsis. MODs is the highest incidence of all cause of death. Sepsis due to antibiotic resistance is almost the cause of death in all ICU hospital department nowadays. In this 3 decades, new antibiotic continuously found, but could not eradicate the Multi Drugs Resistance (MDR) bacteria inside the body. The using of super paramagnetic iron oxide nanoparticles (SPIONs) which induce hyperthermia to kill bacteria has been reported.[1] The using of Ferrite nanoparticles (FNPs) through green synthesis will eradicate all Microbe resistance: MDR, XDR, TDR, inside the human body where body tissue is most transparent to NIR. Shielding by skin melanin, UV kill all resistance bacteria only outside the human body. This study wants to reveal SPIONs green synthesis[2] e.g. from Moringa oleifera gold composite NPs used as photothermal therapy (PTT), based on inducing hyperthermia, to kill bacteria inside the body. The New/Next Generation (NG) MDR eradication, after the racing of new generation antibiotics era, is based on it. Excitation/Emission (Ex/Em) SPIONs semiconductors vs. Photocatalytic agents in coloring/dye water treatment[2,3] mechanism has been recorded. The mechanism of

SPIONs as MRI agent[4] VS. SPIONs AuF based on hyperthermia[1] to kill bacteria,[5] fungi,[6,7] cancer cells,[8] are the same with SPIONs for NG MDR/XDR/TDR antibiotics bacteria inside the human body.[1,5]

II. METHOD

Case report and review on hybrid my library recommendation of Google Scholar, ChatGPT, and academic search engine ScienceDirect, and EBSCOHost MEDLINE with Full Text. Inclusive and exclusive using keywords ITP/AML/MDS laboratory with Bayesian network and Review article using academic search engine My Library, ScienceDirect, and EbscoHost with Bayesian analytical and network of photothermal and hyperthermia induce by SPIONs (Superparamagnetic Iron Oxide Nanoparticles) in association with antimicrobia. Green synthesis was preferable.

III. RESULTS

The mechanism of SPIONs to kill bacteria, fungi, cancer cells has been reported outside and inside human bodies. Kind of spinel ferrite, size, specification, and kind reaction support the argumentation. Source of the semiconductors excitation and emission (Ex/Em) were recorded. The results are focus on SPIONs green synthesis, which have the safety and economic values. The result is on Table 1, is based on these mechanisms:

Antibacterial activities of spinel ferrite nanoparticles (SPIONs) have been reported.[1,5,9,10,11,12, 13,14,15,16,17]

The tests that used to measure the antibacterial properties of zinc ferrite, was 80%, respectively successful. Nanoparticle made of zinc ferrite had a strong antibacterial effect, also the copper ferrite.[18]

Hyperthermia in specific cell with semiconductors which adsorp only Infra Red/Radio Magnetic Resonance,[4,5,19] and do emission of Terahertz T-Ray/Mw.[1,5,9] Whereas Visible/UV light could not be adsorp into the human body cause fail to penetrate the skin melanin shielding.[19]

Emission of hyperthermia could only be in microwaves 1000nm (1mm) – 10 cm (10^{10} Hz-10^{6} Hz). Radiowaves is with lambda more than 10 cm. The frequency of visible light is 4 x 10^{14} Hz till 7 x 10^{14} Hz. Electromagnetic (EM) long wavelength more than 1m or 10^{6} Hz, become a radio wave which is used by TV and radio transmitter, differentiated by the size of the semiconductors. One terahertz is 10^{12} or 1000GHz. Wavelengths of radiation in the terahertz band correspondingly range from 1mm-0.1 mm (100 μm, micrometer). This 1 mm- 100 mm wavelength range tremendously high frequency with frequency range 0.3 THz-3 THz. Terahertz (THz) radiation occupies a middle ground where the ranges of microwaves and infra-red (IR) light waves overlap, known as the 'terahertz gap'. It is called a 'gap' because the technology for its generation and modulation of EM waves in this frequency range ceases to be possible by the conventional electronic devices used to generate radio waves and microwaves, requiring the development of new devices and techniques, including FIR (Far Infra-Red) Ex/Em, the semiconductor SPIONs to make hyperthermia in specific cell to kill cancer cells, and to eradicate MDR/XDR/TDR microbacteria in the body.

Terahertz radiation – also known as submillimeter radiation, terahertz waves, tremendously high frequency, T-rays, T-waves, T-light, T-lux or THz -consists of EM waves within the International Telecomunication Union/ ITU-designated. Milimeter-micrometer-nanometer-pico-femto-atto-zepto-yoctometer is the 7 metric prefixes, and 1 TeraHz is 1000 Giga Hz, then Mega Hz, Kilo Hz etc. Deci Hz = 0.1 Hz, nano Hz = 0.000 000 001 Hz. It is telling the frequency. Whereas <3000 GHz is in ITU designed. Visual wave length: 400-700nm ($7x10^{14}$Hz – $4x10^{14}$Hz). Feel the frequency in ITU with NIR 215-$400x10^{12}$Hz, Microwaves 10^{8}Hz, Radio waves 10^{4}Hz, whereas 1 GHz=10^{9}Hz, and 1000Gz =10^{12}Hz. Photothermal therapeutic (PTT) applications using SPIONs AuFerrite (AuF) based on hyperthermia to kill cells.[1,19]

Photocatalytic for coloring water treatment is on oxidation-reduction reaction is completely different from mechanism of Ex/Em semiconductor SPIONs.

This study is focus on hyperthermia by Ex/Em, but still reported the reported antibiotic based on redox reaction[10,12,] In the second column of table 1, the kind of SPIONs are recorded.

TABLE 1
SIXTEENS INORGANIC NANOPARTICLES (NPS) TO FIGHT FUNGAL AND BACTERIA INFECTIONS IN THE ANTIMICROBIAL RESISTANT ERA: SEMICONDUCTOR BASED

Study, year	Inorganic NPs	Fungal or bacteria	MDR/XDR/TDR/pts status	Source of Excitation
[1]Kharey, 2022	AuF Green synthesis	All Biomedical therapeutic and imaging	MRI, hyperthermia, PTT	~800-1100 nm
[9]Tylor, 2012	SPIONs	AB-resistant biofilm	Multiple bacterial functions	In magnetic field
[5]Billici, 2020	NIR SPIONs	Broad Spectrum antibacteria	PDT	NIR eradication
[10]Rajivgandhi, 2022	Zn and Ni dope CoFNPs	Efficient biofilm eradication	Preparation	Damage of extra polymorphic substances
[11]Rahmayeni, 2021.	ZnF SNPs	Photocatalysis and antibacterial application	Green synthesis	Hydrothermal method
[12]Malik, 2022	NiFe2O4	Anticancer, antibiotic activity	Green synthesis	Oxidative stress
[13]Omelyanchik, 2020	Green Co-Zn SF NPs	Intrinsic Antimicrobial Properties	Green synthesis	Magnetic
[14]Subbiahdoss, 2012	FNPs	Antibacterial agents gentamycin-resistance staphylococci	Hyperthermia SPIONs	Magnetic targeting of surface-modified
[15]Kombaiah, 2017	FNPs	Antimicrobial properties	Green synthesis	Optical Magnetic
[6]Kumar, 2021	Carrageenan NPs	Fungicide by thermal behavior	Biopolymeric Chitosan-Carrageenan nanocomposites 66-231 nm	Soil and water pollution
[7]Madkhali, 2023	Metallic NPs e.g. AuNPs Zinc oxide etc. CnT	Potent Antifungal Rx/ to combat human fungal diseases incl. Candida, Aspergillus	Invasive fungal infections mortality and morbidity	Disturb mitochondrial calcium homeostasis
[8]Niemirowick, 2017	Magnetic NPs	Antifungal Anti cancer agents	Induce Hyperthermia	Enhance photosensitizing processes
[20]Hosseini, 2018	beyond Neutron source and gamma-ray	Deep seated tumor	PDT	X-ray induce photodynamic therapy (PDT)
[16]Hu, 2023	Photo sensitizers	Antimicrobacterial	APDT can kill drug-resistant strains, fungi, and viruses	Photo sensitizers with light activation
[17]Dove, 2023	AgNPs	Antibiotic-resistant bacteria	Reduced the minimum inhibitory levels of aminoglycoside	
[19]Liu, 2023	AgNPs	Kill cancer and bacteria cells directly	PTT	Adsorp 800 nm (NIR) laser for heat generation

The PTT making hyperthermia to kill the cells[1,19] but many outside killing reported as redox reaction, the making of Reactive Oxygen Species (ROS) that kill the bacteria, the resistant bacteria.

IV. DISCUSSION

Various nanoparticles have designed and made with the aim to kill cancer cell and bacterial cell. Ferrites, a kind of ferrimagnetic ceramic with the formula of spinel ferrite MFe_2O_4 (M is bivalent metal ion, like Zn, Cu, Ni, Co, Fe, and Mn) are recognized for their great chemical stability, electrical resistance, has magnetic and physical characteristic. As a semiconductor, spinel ferrite has unique qualities like thermal and chemical stability and the dependency of magnetic characteristics on particle size in offering in hyperthermal technical applications. Made by green methods has reported to kill bacteria, incl. antibiotic resistance microbacteria (similar size as mitochondria). With the hyperthermal technical applications, these MDR, XDR, TDR antibacterial where the terminal case of multi-organ damage (MODs) in sepsis, should have been cured on sepsis and pre-sepsis cases. In the human body, the Excitation (Ex) should be with IR, and outside the body could be by UV natural from sun light or from UV lamp. As semiconductors, each size will emit certain electromagnetic wave, needs in T-ray range (hyperthermia), which will kill the bacteria. It is like a semiconductor that use by a radio or television principle. How to insert the semiconductors in the bacteria will be in another articles, but could be like insertion of MRI agent using SPIONs[1,4] with the Excitation being radio-wave with magnetic resonance. Nowadays these biological and industrial green synthesis of SPIONs for MRI agents,[4] and killing cells inside the body are in economic value in INDUSTRY 4.0.

This study focusses on green synthesis extracted form leaves, but the other method of synthesis preparation sol-gel processing, citrate decomposition, wet-milling method, solid-state reaction, hydrothermal crystalline, coprecipitation, and polymer matrix precipitation, were also used to create the spinal ferrites. The supporting mechanism of killing microbacteria are as followed:

1. Cobalt ferrite,[4] Cooper ferrite,[18] Zinc ferrite,[7,11] Nickel ferrite[10] Excitation, by UV (superficial) not IR (through inside the body), depends on the source of excitation, the emission of hyperthermia (T-ray) depends on the size of the Ferrite Nanoparticles (FNPs). Photocatalytic size,[11,21] is bigger than size for the hyperthermia emission.[1] For both, uses[11] has been reported. Killing by Photothermal Therapy (PTT) inducing hyperthermia[1,17] under NIR irradiation.[1,5,19]

2. Inserting the semiconductor/SPIONs-MRI agent e.g. for the treatment of antibiotic-resistant biofilm, and GMF-Antibiotic Marker Genes,[9,24] which is used in the making of superior seeds.[24]

3. Photothermal Therapy (PTT)[1,9,19] is different to PDT for killing cancer cell.[12,22] The mechanism of PTT is also different than cancer diagnosis, target drug delivery, and treatment, which are no need of the making of hyperthermia.

4. Photo Dynamic Therapy (PDT) to kill, not to taken MRI image,[4] and MRI of infection and inflammation.

5. Bacteria (similar size as mitochondria), are killed in hyperthermal technical applications in antibiotic resistance microbacteria using NPs. Green Synthesis of AuNPs is used to kill.[1]

   Researchers are always looking for new PDT drugs, and new ways to give therapy. So do the New Drugs SPIONs/ FNPs to kill MDR/TDR/XDR micro-bacterial inside the body and cancer cells. A new PTT drugs that can target tumor cells better, can leave normal cells more quickly, and allow the treatment light to penetrate better, not only in agarose gel Petry dish.

   AuNPs from Pimenta dioica aqueous leaf extract for PTT.[1] And Cobalt doped and MgF SNPs From Moringa Oleifera,[3] later could be doped to another FNPs e.g. Zn and Ni for efficient biofilm eradication (antibiotic resistance).[10]

6. Beta lactams antibiotics killing beta-lactamase bacteria, and beta-lactamase inhibitors[23].

   Before this hyperthermia SPIONs for killing micro bacteria, beta-lactams and beta-lactamase inhibitors are conquering antibiotic pharmaceutical industry.

The single antibacterial weapons most prescribed antibiotic class and the top important in terms of sales is the beta-lactams, but still failed in the sepsis and pre-sepsis stage. It could years after beta-lactamases, in and out the hospital, and the last stage are MODs and Steven Johnson syndrome, an immune-complex-mediated hypersensitivity. Four main classes of beta-lactam antimicrobials are in clinical use, which consist of three types of bicyclic structure: the penicillin, the cephalosporins, the carbapenems, and monobactams. Each class are originally a natural product. Each has since undergone semi-synthetic derivatives. Ampicillin and methicillin are an extended antibacterial activity of penicillin i.e., Gram-negative bacteria (ampicillin), and to counter resistant strains of Staphylococcus aureus (methicillin).[23] Penicillins are contraindicated in patients with history of anaphylactic reactions or serious skin reactions, for example, Stevens-Johnson syndrome and toxic epidermal necrosis.

4.1 The beta-lactam resistance:

There are Class A, C, D, and metallo-beta-lactamases (MBLs; class B).[23] Divers class of this enzymes produced by bacteria that inactivating the beta-lactam antibiotic. Mobile genetic elements (MGE) e.g. GMO with antibiotic resistance marker genes (ARMGs). encoded in RNAi or on chromosomes.[24] These RNAi are inserted in superior seed to silence the non-demand characteristic quality of form, color, size, etc. to be change to better wish. ARMGs is used to separate the successful inserted from the failed, because ARMGs is coupled with the part of the wishes inserted gene, and kanamycin ARMGs has been reported.[24] Extended-spectrum beta-lactamases (ESBL) which are produced by Gram-negative bacteria also needs to be covered by SPIONs PTT, whereas Carbapenems are one of the few remaining antibiotics that can treat ESBL-producing germs, but resistance enzymes that destroy these antibiotics are on the rise, too. Medicolegal trained all doctors incl. veterinarian to have indication to give antibiotics, and not giving for prevention, but it fail to provide for plants.[24] Methicillin resistant staphylococcus aureus (MRSA) is resistant to all beta-lactam antibiotics and many commonly used antibiotic groups. Multidrug-resistant (MDR) TB are resistant to at least isoniazid and rifampin, the two most potent TB drugs. XDR-TB is a rare type of MDR TB that is resistant to isoniazid, rifampin, a fluoroquinolone, and second-line injectable e.g. Kanamycin. Total drug-resistant TB (TDR-TB) is resistant to a wider range of drugs than strains classified as extensively drug-resistant TB.

4.2 The beta-lactamase Inhibitors (BLI):

The BLI represent the major strategy for combating b-lactamase-mediated resistance. Clavulanic acid as an irreversible inhibitor of the most widely distributed class A enzymes. Penicillin-inhibitor combinations have found wide application as treatments for healthcare-associated infections by beta-lactamase-producing organism (the resistance one). The BLI is now necessary better treatment options for beta-lactamase-producing microorganism NG.[23]

4.3 MDR to multi-organ damage (MODs):

The new application of new antibiotic drug discovery is pressed by antimicrobial new resistance now with the high prevalence of MODs as terminal cases of sepsis. Prevention of MODs as the cause of dead in almost hospital ICU due to sepsis, has to change the focus on hyperthermia mechanism to kill the microbial resistant. This review study is the first SPIONs green synthesis to kill microbial resistant inside the body incl. killing Betalactamases and betalactamase inhibitors.[23] The SPIONs semiconductors kill by inducing hyperthermia,[1,9] under NIR irradiation.[5,19] Their heating performance came from wavelength range of ~800-1100 nm which is a tissue-transparent NIR region.[1]

Using inorganic NPs to fight fungal infections in the antimicrobial resistant era,[25] and the effect of decorating SPIONs with Ag NPs on their Magneto-Photo Thermal Heating Efficacy,[1,7,19] become the solution of all MDR, XDR, TDR microbacteria in this sepsis-MDO era.[14,16,17,19] The SPIONs gold composite for MRI contras agent, hyperthermia, and photothermal therapy (PTT) application has been reported.[1,19]

V. LIMITATION

Removal of antibiotic in an antibiotic manufacture sewage similar mechanism to photocatalytic process in coloring dye (e.g. methylene blue) as photodegradation on organic pollutans, has a different principle with antimicroba.[1,16,17,19] In this study we limit the photodegradation, and focus on hyperthermia principle on antimicroba. Then this study do not discuss how ARMGs to make superior seed using RNAi[24] but focus on killing MDR/TDR/XDR, the beta-lactamase-producing organism (the resistance one) using SPIONs crystals.[9]

The using of SPIONs for the treatment of Antibiotic-Resistant Biofilms using SPIONs.[9,10,14]

SPIONs as MRI agent,[1,4] or as drug carriers (vector), are also limited, and focus as MRI agent of infection and inflammation, and hyperthermia to antibacteria.

The Photocatalytic and Antibacterial Activity Cobalt Ferrite from plant extract,[1,5,13,15] Magnetic and Intrinsic Antimicrobial Properties,[13] and other SPIONs activity non PTT are not specific included in this study.

The author also limits to the other green synthesis SPIONs similar to moringa oleifera, such as aloe vera, Psidium guajava tea, sea grass, etc. The limitation of SPIONs in Moringa oleifera has specify the basic principle mechanism on PTT to eradicate resistant microbacteria inside the human body in low cost.

Aqueous extract Moringa oleifera leaves (CuNPs) has antifungal activity, Carrageenan Nanoparticles against Phytopathogenic Fungi,[6] metallic nanoparticles as antifungal therapies non PTT to combat human fungal diseases.[7] Magnetic NPs candidacidal activity,[8] and killing cancer cells[8,12,19] are also limited.

Broad Spectrum antibacteria by PDT achieved with SPIONS under NIR irradiation were reported,[5] and also in PTT applications.[1,9,16,17,19] A PDT were also used in cancer cell therapy achieved with SPIONs,[8,12,16,19] mix PTT with Radiotherapy,[20] and disturb metabolism enhance the efficacy of aminoglycosides against antibiotic-resistant bacteria,[17] and oxidative stress[12] has been limited.

This is the first review study reveal PTT achieved with SPIONs, excitation by NIR using to kill MDR, XDR, TDR, and other resistant microbial inside the body, to fight sepsis and MODs as early as possible. The using of SPIONs to fight fungal in the antimicrobial resistant era has also been reported.[25]

VI. CONCLUSION

SPIONs green synthesis gold composite NPs are used as NIR photothermal therapy based on inducing hyperthermia to kill bacteria inside the body: NG MDR bacteria eradication, prevent MODs in sepsis.

ACKNOWLEDGEMENTS

The first author is thankful to University of Indonesia, Faculty of Medicine for supporting the leaf to prepare the extract to make SPIONs. The author would like to thank Cyber Police, BRIN, and LinkedIn for bringing back all her puzzle, her ORCID Mine should be the authors articles which is lost and spread in many clones of mine. The author would also like to acknowledge and sincerely thank Dr. Sebayang, JPHRECODE for keep being exist of our ORCID ID and our GARUDA ID. Staff with Dr. Rahyusalim, manager of research FMUI for keeping the first author record in seminar, although the international journal article is still Null. Dr. Peni K. Samsuria Mutalib would further like to acknowledge the Direktorat RPM and Direktorat Sumber Daya, Government of Indonesia for giving me Teaching Certification. Also Indonesian Ministry of Health in the Omnibus Law who open report of doctor's persecution, hope also works for all education staff in Medical Education Graduate in persecution, grooming and phishing and erase all their works. The author also thanks FEB (Faculty Economy and Business) which is using the institutional network IT to the top SCOPUS ID journals, and supporting the growing of many authors.

CONFLICT OF INTEREST

Nothing financial interest

REFERENCES

[1] Kharey P, Goel M, Husain Z, Gupta R, Sharma D, Palani MIA, Gupta S. Green synthesis of biocompatible superparamagnetic iron oxide-gold composite nanoparticles for magnetic resonance imaging, hyperthermia, and photothermal therapeutic applications. Mater Chem and Phys 2022; 9:126859. https://doi.org/10.1016/j.matchemphys.2022.126859

[2] Ijaz I, Gilani E, Nazir A, and Bukhari A. Detail review on chemical, physical and green synthesis, classification, characterizations and applications of nanoparticles. Green Chem Letters and Rev 2020;13(3):223-45. https://doi.org/101080/17518253.2020.1802517

[3] Khodashenas B, Ghorbani HR. Synthesis of silver nanoparticles with different shapes. Arabian Journal of Chemistry 2019; 20(8):1823-38. https://doi.org/10.1016/j.arabjc.2014.12.014

[4] Mohammadi Z, Attaran N, Sazgarnia A, Shaegh SAM, Montazerabadi A. Superparamagnetic cobalt ferrite as T2 contrast agent in MRI. IET Nanobiotechnol 2020; 14(5): 396-404. https://doi.org/10.1049/iet-nbt.2019.0210

[5] Bilici K, Atac N, Muti A, Baylam I, Dogan O, A. Sennaroglu A, et al. Broad spectrum antibacterial photodynamic and photothermal therapy achieved with indocyanine green loaded SPIONs under near infrared irradiation. Biomater Sci 2020; 8(16): 4616-25.

[6] Kumar R, Najda S, Duhan JS, Kumar B, Chawla P, Klepacka J, et al. Assessment of Antifungal Efficacy and Release Behavior of Fungicide-Loaded Chitosan-Carrageenan Nanoparticles against Phytopathogenic Fungi. Polymer (Basel) 2021;14(1):41. https://doi.org/10.3390/polym14010041

[7] Madkhali OA, A Comprehensive review on potential applications of metallic nanoparticles as antifungal therapies to combat human fungal diseases. Saudi Pharmaceutical Journal 2023;31(9): 101733. https://doi.org/10.1016/j.jsps.2023.101733

[8] Niemirowick K, Durnas B, Piktel E, Bucki R. Development of antifungal therapies using nanomaterials. Nanomedicine (Lond) 2017;12(15):1891-1905. https://doi.org/10.2217/nnm-2017-0052

[9] Tylor EN, Kummer KM, Durmus NG, Leuba K, Tarquinio KM, Webster TJ. Superparamagnetic iron oxide nanoparticles (SPION) for the treatment of antibiotic-resistant biofilms. Small 2012; 8(19):3016-27. https://doi.org/10.1002/smll.201200575

[10] Rajivgandhi G, Ramachandran G, Chackaravarthi G, Chelliah CK, Maruthupandy M, Quero F, et al. Preparation of antibacterial Zn and Ni substituted cobalt ferrite nanoparticles for efficient biofilm eradication. Analytical Biochemistry 2022, 15 Sept; 653: 114787. https://doi.org/10.1016/j.ab.2022.114787

[11] Rahmayeni, Febrialta R, Setiadi Y, Putri YE, Sofyan N, Zulhadjri. Simbang Darah (Iresine herbstii) extract mediated hydrothermal method in the synthesis of Zinc Ferrite spinel nanoparticles used for photocatalysis and antibacterial applications. J Envi Chem Eng 2021; 9(2);105140. https://doi.org/10.1016/j.jece.2021.105140

[12] Malik AR, Aziz MH, Atif M, Irshad MS, Ullah H, Gia TN et al. Lime peel extract induced NiFE2O4 NPs: Synthesis to applications and oxidative stress mechanism for anticancer, antibiotic activity. J of Saudi Chem Soc 2022;26(2): 101422. https://doi.org/10.1016/j.jscs.2022.101422

[13] Omelyanchik A, Levada K, PshenichnikovS, Abdolrahim M, Baricic M, Kapitunova A, et al. Green Synthesis of Co-Zn Spinel Ferrite Nanoparticles: Magnetic and Intrinsic Antimicrobial Properties. Mater (Basel) 2020;13(21):5014. https://doi.org/10.3390/ma13215014

[14] Subbiahdoss G, Sharifi S, Grijpma DW, Laurent S, van der Mei HC, Mahmoudi M, Busscher HJ. Magnetic targeting of surface-modified superparamagnetic iron oxide nanoparticles yields antibacterial efficacy against biofilms of gentamycin-resistance staphylococci. Acta Biomater 2012;8(6):2047-55. https://doi.org/10.1016/j.actbio.2012.03.002

[15] Kombaiah K, Vijaya J, Kennedy LJ, Bououdina M, Ramalingam RJ, Al-Lohedan H. Okra extract assisted green synthesis of CoFe2O4 nanoparticles and their optical, magnetic, and antimicrobial properties. Mat Chem Phys 2017;204: 410-9. https://doi.org/10.1016/J.MATCHEMPHYS.2017.10.077

[16] Hu X, Shou B, Yong L, Li L, Ren H-T, Lin J-H, et al. Antimicrobial photodynamic therapy encapsulation technology: Frontier exploration and application prospects of novel antimicrobial technology. Chem Engin J 2023:477:146773. https://doi.org/10.1016/j.cej.2023.146773

[17] Dove AS, Dzumy DI, Dees Wr, QinN, Nunez Rodriguez CC, Alt LA, et al. Silver nanoparticles enhance the efficacy of aminoglycosides against antibiotic-resistant bacteria. Front Microbiol 2023; 13:1064095. https://doi.org/fmicb.2022.1064095

[18] Moustakas M, Malea P, Haritonidou K, SperdouliI. Cooper bioaccumulation, photosystem II functioning, and oxidative stress in the seagrass Cymodocea nodosa exposed to copper oxide nanoparticles. Environ Sci Pollut Res Int 2017; 24(19):16007-16018. https://doi.org/10.1007/s11356-017-9174-3

[19] Liu S, Phillips S, Northrup S, Levi N. The impact of Silver Nanoparticle-Induced Photothermal Therapy and Its Augmentation of Hyperthermia on Breast Cancer Cells Harboring Intracellular Bacteria. Pharmaceutics 2023;15(10):2466. https://doi.org/10.3390/pharmaceutics15102466

[20] Hosseini W, Mirrahimi M, Shakeri-Zodeh A, Koosha F, Ghalandari B, Maleki S, KomeiliA, Kamrava SK. Multimodal cancer cell therapy using Au@Fe2O3 core-shell nanoparticles in combination with photo-thermo-radiotherapy. Photodiagnosis Photodyn Ther 2018; 24: 129-35. https://doi.org/10.1016/j.pdpdt.2018.08.003

[21] Kaur N, Kaur R, Singh S. Size-Dependent Structural, Optical and Photocatalytic Properties of Zirconium Ferrite Prepared via a Sol-Gel Route. ChemistrySelect 2023 July 04; 8(25): 2202300829. https://doi.org/10.1002/slct.202300829

[22] Vangijzegem TV, Lecomte V, Ternad I, van Leuven L, Muller RN, Stnicki D, Laurent S. Superparamagnetic Iron Oxide Nanoparticles (SPIONs): From Fundamentals to State-of-the-Art Innovative Applications for Cancer Therapy. Pharm 2023:15(1): 236. https://doi.org/10.3390/pharmaceutics15010236

[23] Tooke CL, Hinchliffe P, Bragginton EC, Colenso CK, Hirvonen VHA, Takebayashi Y, Spencer J. β-Lactamases and β-Lactamases Inhibitors in the 21st Century. J Mol Biol 2019; 431(18): 3472–3500. https://doi.org/10.1016/j.jmb.2019.04-002

[24] HK gov. Genetically Modified Food-Antibiotic Marker Gene. Centre for Food Safety, HK government 2009. https://www.cfs.gov.hk/english/multimedia/multimedia_pub/multimedia_pub_fsf_37_02.html

[25] Huang T, Li X, Maier M, O'Brien-Simpson NM, Heath DE, O'Connor AJ. Using inorganic nanoparticles to fight fungal infections in the antimicrobial resistant era. Acta Biomater. 2023 Mar 1:158:56-79. https://doi.org/10.1016/j.actbio.2023.01.019.

Biotechnological Innovations in Packaging and Sensors in the Food Processing

Pooja P. Thul[1*]; Dr. D. N. Jagtap[2]; Rinkesh A. Gosavi[3]; Manjit M. Khatal[4]; Prajakta Labade[5]; A. A. Sawant[6]

[*1,3]PhD Scholar, Department of Processing and Food Engineering, CAET, Dr. BSKKV, Dapoli, Ratnagiri, M. S. (India)
[2]Assistant Professor, Department of Agronomy, COA, Dr. BSKKV, Dapoli, Ratnagiri, M. S. (India)
[4]Young Professional, ICAR-Directorate of Onion and Garlic Research, Pune, Maharashtra, India
[5]PhD Scholar, Department of Soil and Conservation Engineering, CAET, Dr. BSKKV, Dapoli, Ratnagiri, M. S. (India)
[6]Professor and Head, Department of Processing and Food Engineering, CAET, Dr. BSKKV, Dapoli, Ratnagiri, M. S. (India)
*Corresponding Author

Received:- 08 April 2025/ Revised:- 16 April 2025/ Accepted:- 21 April 2025/ Published: 30-04-2025

Abstract— *The global bioplastics and biopolymers market size is expected to grow from USD 10.5 billion in 2020 to USD 27.9 billion by 2025, Bioplastics and Biopolymers Market by Type (Non-Biodegradable/Bio-Based, Biodegradable), End-Use Industry (Packaging, Consumer Goods, Automotive and Transportation, Textiles, Agriculture and Horticulture), and this high growth is driven primarily by the growth of the global packaging end-use industry. Food packaging has a crucial function in the modern food industry. New food packaging technologies seek to meet consumers' and industrial demands. Changes related to food production, sale practices and consumers' lifestyles, along with environmental awareness and an advance in new areas of knowledge such as biotechnology, act as driving forces to develop smart packages that can extend food shelf-life. Food producers gradually demand effective quality control procedures to satisfy and regulate consumer requirements to enhance production feasibility, automation, quality sorting and decrease the time and cost of production. Biosensors can be used to identify food allergens and pathogens rapidly and efficiently. It can also overcome all these disadvantages by offering quick, inexpensive and non-destructive procedures for quality control.*

***Keywords*— Bioplastics, Biopolymers, Packaging, Biosensors, Allergens, Pathogens.**

I. INTRODUCTION

Fresh food products get easily degraded due to physical injuries resulting from handling, transportation, storage, or intrinsic factors caused by chemical reactions, enzyme action, and microbial spoilage. The use of packaging is therefore a strategic choice for protecting and conserving food (Rodrigues et al., 2021). Packaging has four basic functions, viz., Containment, convenience, protection and communication. Food packaging is a vital element of the food industry, as it supports all operations associated with the processing, handling, transport, and distribution of the contained food (Marangoni Junior et al., 2022). In today's food industry, packaging is a foundation that performs several important tasks to ensure product quality and consumer safety. It acts as a shield and protects against external elements such as bacteria, insects, light, heat, oxygen and odours, thus preserving the food during its shelf life. In addition to this basic function, it also serves as a means of communication with consumers. It conveys important information through labels, branding and design, meeting the convenience and time-saving needs of today's consumers (Bhatlawande et al., 2023).

Generally, packaging is classified based on the material type used for packaging, which can be divided into metal, glass, polymer, paper cardboard, wood, textile, multi-layered, ceramic and other types (Ivankovic et al., 2017). Over half a century, plastic packaging has prevailed owing to its versatility and cost-effectiveness, eclipsing traditional materials such as glass, metal, paper, and cardboard. As a result of their non-biodegradable nature and pollution generated throughout their life cycle, petroleum-based plastics have catalysed a cascade of environmental concerns. In response to these pressing issues, the industry is undergoing a rapid transition towards eco-friendly packaging, with biodegradable and bioplastic materials, derived from biomass and characterized by their biodegradability, gaining remarkable traction (Bhatlawande et al., 2023). Biodegradable and renewable materials represent a great alternative for protecting the environment and transforming underutilized products or industrial waste materials into valuable products. In this sense, bioplastics have begun to gain prominence (Salgado et al., 2021).

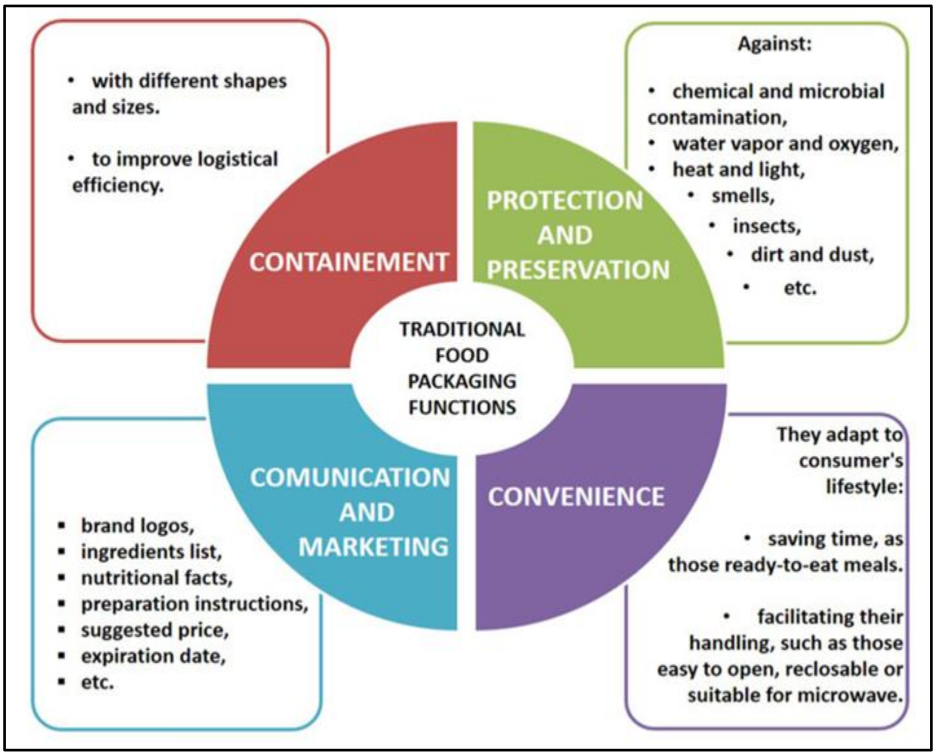


FIGURE 1: Traditional food packaging functions (Salgado et al., 2021)

II. BIOTECHNOLOGY

Biotechnology is a multidisciplinary field that integrates natural and engineering sciences to achieve the application of organisms and parts thereof for products and services. The term biotechnology refers to the production of products from raw materials with the aid of living organisms. The core principle of biotechnology involves harnessing biological systems and organisms, such as bacteria), and plants, to perform specific tasks or produce valuable substances (Biotechnology, Wikipedia).

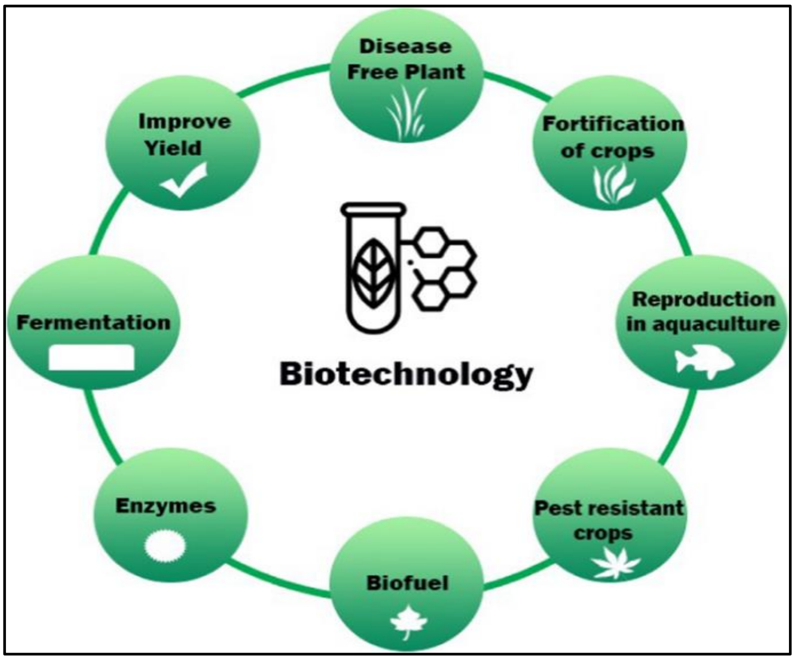


FIGURE 2: Biotechnology in Food and Agriculture (Ranjha et al., 2022)

2.1 Biotechnology in food processing:

Biotechnology is a branch of science concerned with the utilization of various living organisms in the creation of useful products. It can be defined as any technological application that uses biological systems, living organisms, or derivatives to produce or modify products or processes for specific use. Biotechnology integrates animals, humans, and microorganisms that have contributed to every aspect of our lives. It has opened numerous opportunities to various sectors such as food technology, agriculture, animal sciences, cell biology, plant sciences, environmental sciences, and medicine. For example, food technology is not only an important but a promising research area that applies biotechnology tools to improve the oldest food processing techniques such as fermentation, enzyme production, as well as conservation of plants (Yu, 2017).

In the food processing sector, biotechnology plays a crucial role, especially in cereal processing, fruit and vegetable processing, beverages, oils and fats, dairy processing, poultry and confectionary processing. Nowadays, biotechnology is used in every aspect of life (Ghoshal, 2018). It can convert non-edible and perishable food items to palatable and longer shelf-life food, which is safe and improved quality in terms of nutrition and physicochemical and sensory properties. Through the use of modern biotechnology in the food industry, the reduction of food losses has not only been made possible but the efficiency of food quality has also been improved (Awulachew, 2021).

2.2 Potential Areas for Biotechnological Applications in Food Processing:

The food processing industry has several potential areas where traditional and modern biotechnological tools can be applied during processing to enhance the nutritional quality, safety and health-promoting attributes of processed foods, particularly dairy-based fermented foods. Some of the potential areas of considerable commercial interest in the food processing industry that can be targeted for biotechnological interventions are listed below:

1. Food fermentations
2. Starter cultures technology and genetic manipulation
3. Recombinant Enzymes
4. Bio-preservation of foods
5. Functional / Health foods and Nutraceuticals
6. Probiotics, prebiotics and symbiotic foods
7. Genetically modified foods (GM Foods)
8. Milk-derived bioactive peptides and other functional ingredients
9. Low calorie foods
10. Food packaging
11. Diagnostic tests for food safety and quality assurance
12. Biosensors (Evans and Furlong, 2003)

Traditionally, food packaging protects foods from physical, chemical, and biological factors, maintains quality, and facilitates distribution and marketing (Jacob et al., 2020). In recent years, plastic packaging has proven to be one of the most versatile polymer materials due to its unique mechanical properties, high functionalities, and relatively low costs. A global packaging market of USD 1002.48 billion was estimated in 2021, and it is expected to reach USD 1275.06 billion in 2027 (Anonymous[2], 2022). Global plastic waste generated from 2000 to 2019 has more than doubled to 353 million tons, with packaging contributing approximately 40% (Anonymous[3], 2022). Recently, various countries have taken bold steps to manage plastic packaging waste. Biotechnology has emerged as a viable solution (Fig. 3) for engineering biodegradable, active, and functional polymers/bioplastics for use in food packaging system design, development of edible films/coatings, and packaging technologies (Alim et al., 2022; Caleb and Belay, 2023).

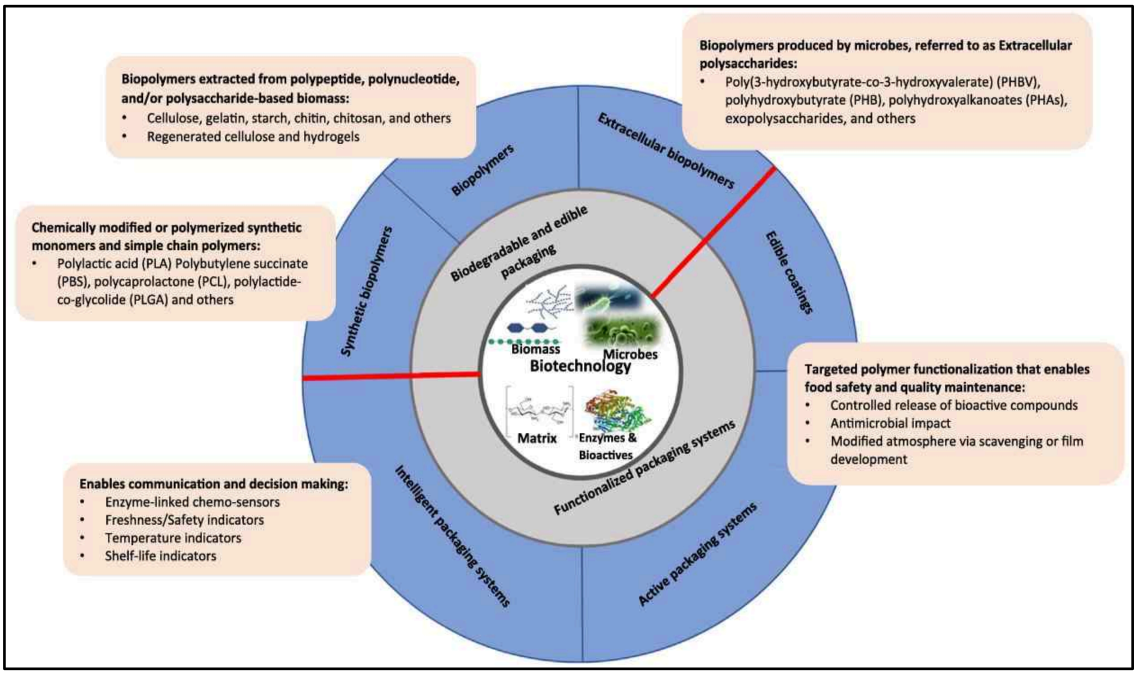


FIGURE 3: Role of biotechnology in food packaging systems (Caleb and Belay, 2023)

2.3 Biopolymer:

Biopolymers are polymers that are developed from living organisms. The term " biopolymer" implies a biodegradable polymer. A biopolymer has existed on earth for billions of years and is much older than synthetic polymers such as plastic. They are compounds prepared by using various living organisms, including plants. Biopolymers are composed of repeated units of the same or similar structure (monomers) linked together. Rubber, starch, cellulose, proteins and DNA, RNA, chitin, and peptides are some examples of natural biopolymers. Biopolymers are a diverse and remarkably versatile class of materials that are either produced by biological systems or synthesized from biological sources. Biopolymers are used in the food and pharmaceutical industries (Upadhye et al., 2022).

The Biopolymers Market size is projected to reach US$27.5 billion by 2030, after growing at a CAGR of 11.5% over the forecast period 2024-2030. The various benefits associated with biopolymers such as polyesters, polylactic acid, polyhydroxy butyrate, polybutylene succinate and more include biocompatibility, biodegradability, renewability and more. These benefits make biopolymers a sustainable replacement for petroleum-derived materials. The bolstering food and beverage industry, including poultry products, dried food and more is the primary factor driving the biopolymers market growth [Biopolymers Market – Forecast (2024 - 2030)].

2.5.1 Biopolymer in the food industry:

Biopolymers are increasingly being explored and utilized in the food industry due to their biodegradability, renewable sources, and potential to replace synthetic polymers. They offer a range of applications including packaging, edible coating and ingredients to enhance the nutritional and functional properties of food. The use of biopolymers as packaging materials is becoming an emerging trend worldwide due to their major benefits over plastics, such as biodegradability, eco-friendly nature, nontoxicity, and biocompatibility. In recent years, numerous biopolymers such as starch, chitosan, carrageenan, polylactic acid, etc. have been investigated for their potential application in food packaging. The trend of using biopolymers in the packaging industry has increased immensely; therefore, many legislations have been approved by various organizations (Horst et al., 2020; Perera et al., 2022).

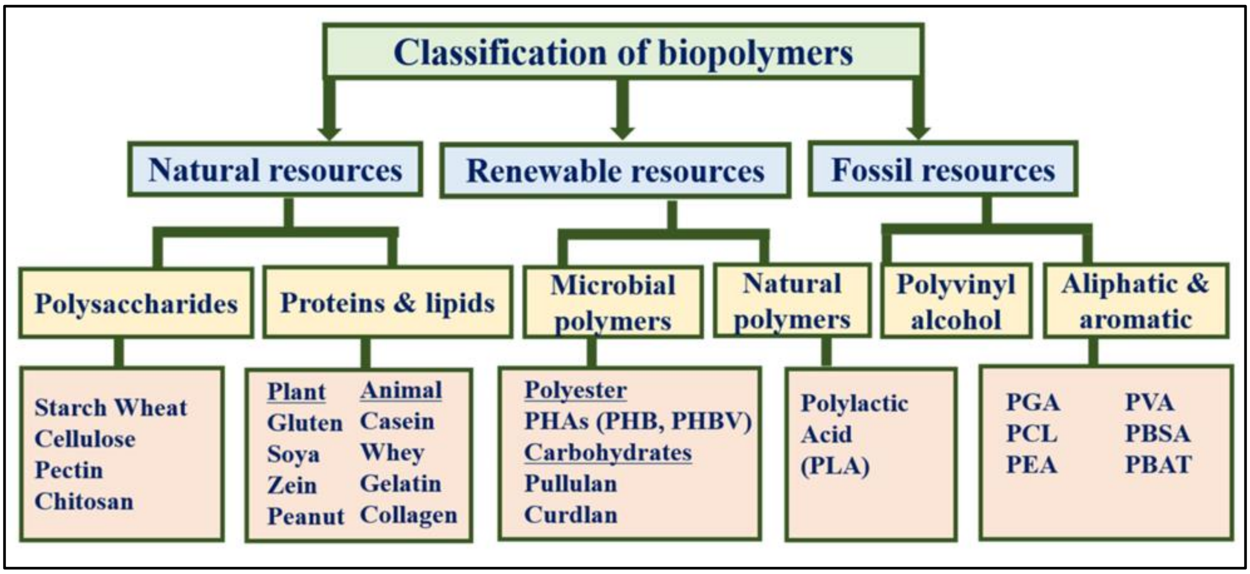


FIGURE 4: Classification of biopolymers for food packaging applications (Basavegowda and Baek, 2021)

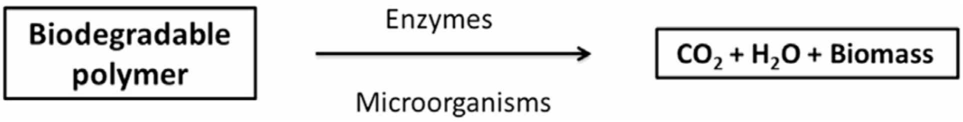
TABLE 1
VARIOUS BIOPOLYMERS AND THEIR APPLICATIONS IN THE FOOD INDUSTRY

Biopolymer	Source	Applications in Food Industry	References
Starch	Corn, potatoes, wheat	Edible films, biodegradable packaging, thickeners, stabilizers	Tako et al., 2020
Chitosan	Shellfish exoskeletons	Antimicrobial films, food coatings, preservative agents	Ravi Kumar, 2000
Alginate	Brown seaweed	Gelling agent, encapsulation of flavors and probiotics, edible films	Draget et al., 2005
Pectin	Citrus peels, apple pomace	Gelling agent, stabilizer, thickener, edible films, encapsulation	Voragen et al., 2009
Gelatin	Animal bones, skin, connective tissue	Gelling agent, stabilizer, film-forming agent, encapsulation	Karim and Bhat, 2009
Carrageenan	Red seaweed	Thickener, gelling agent, stabilizer, film-forming agent	Necas and Bartosikova, 2013
Polylactic Acid (PLA)	Fermented plant starch (corn, sugarcane)	Biodegradable packaging materials, disposable cutlery, food containers	Auras et al., 2004
Polyhydroxyalkanoates (PHA)	Bacterial fermentation	Biodegradable packaging, food service ware	Chen, 2010
Pullulan	Fermentation of starch by fungus	Edible films, coatings, capsules	Singh et al., 2008
Xanthan Gum	Fermentation by Xanthomonas campestris	Thickener, stabilizer, emulsifier, gelling agent	Garcia-Ochoa et al., 2000

2.5.2 Biodegradation of biopolymer:

Biopolymers or biodegradable polymers are renewable natural resources derived from biological systems, such as plants, animals, and microorganisms, and/or chemically synthesized from the starting materials of natural fats, sugars, and starch (Pawar and Purwar, 2013). Natural biopolymers are alternatives to synthetic polymers generated from non-renewable petroleum resources. Biodegradation of biopolymers is an essential process in the natural environment, where microorganisms break down biopolymers into smaller molecules, eventually converting them into carbon dioxide, water, and biomass (Folino et al., 2020).

The process of biodegradation is based on the fact that microorganisms (bacteria, fungi, and algae) identify the polymer as a source of organic building blocks and a source of energy they need for life. Simply put, biodegradable polymers represent food to microorganisms. The polymer chemically reacts under the influence of either cellular or extracellular enzymes whereby the polymer chain is split. The process can take place under the influence of a variety of enzymes and gradually leads to smaller molecules. Thus, different mechanisms can be involved in the degradation process that comprises physical, chemical, and biological processes.



Environmental factors not only regulate polymer degradation but also have a crucial impact on the microbial population and the various microorganisms' activity. Parameters such as humidity, temperature, pH, salinity, presence or absence of oxygen, and the supply of various nutrients significantly influence the microbial degradation of polymers (Nair et al., 2017).

TABLE 2
BIODEGRADATION OF BIOPOLYMERS

Biopolymer	Mechanism of Biodegradation	Microorganisms	References
Polylactic Acid (PLA)	Hydrolysis followed by microbial assimilation; enzymatic breakdown into lactic acid	Bacillus brevis, Amycolatopsis sp., Thermus thermophilus	Tokiwa and Calabia (2006)
Polyhydroxyalkanoates (PHA)	Enzymatic hydrolysis by PHA depolymerase into monomers (e.g., 3-hydroxybutyrate)	Pseudomonas lemoignei, Alcaligenes faecalis	Jendrossek (2009)
Polycaprolactone (PCL)	Hydrolytic degradation followed by microbial assimilation	Fusarium solani, Penicillium sp., Aspergillus sp.	Tokiwa and Calabia (2006)
Starch-based polymers	Enzymatic degradation by amylases into oligosaccharides and glucose	Bacillus subtilis, Aspergillus niger, Rhizopus arrhizus	Bastioli (2005)
Cellulose-based polymers	Enzymatic hydrolysis by cellulases into glucose	Trichoderma reesei, Phanerochaete chrysosporium, Cellulomonas fimi	Lynd et al. (2002)
Chitosan	Enzymatic hydrolysis by chitosanases and deacetylases into glucosamine	Streptomyces griseus, Aspergillus niger	Rinaudo (2006)
Polybutylene succinate (PBS)	Hydrolytic degradation followed by microbial assimilation	Fusarium solani, Penicillium sp.	Tokiwa and Calabia (2006)
Polyethylene terephthalate (PET)	Partial degradation by hydrolases; often requires pretreatment	Ideonella sakaiensis, Thermobifida fusca	Yoshida et al., (2016)

2.4 Current food packaging material and associated issues:

Food packaging materials play a crucial role in maintaining food quality, extending shelf life and ensuring safety. Plastic, an oil-based, versatile and ubiquitous material, is widely used in food packaging due to its lightweight, cost-effective, transparent, versatile and easy-to-process properties. These synthetic polymers have excellent mechanical, thermal and barrier properties, while ultra-thin layers extend the shelf life of packaged products and reduce food waste (Dong et al., 2021). Thus, plastics provide a direct economic benefit by reducing transportation costs.

Global plastic production has increased significantly, with 40% of all produced plastic being used for packaging, and almost half for food packaging. However, plastic's high production rate, short usage time, non-biodegradable nature, and inadequate handling have raised concerns worldwide, with recycling challenges arising from multilayer plastics (Perera et al., 2022).

Plastic waste damages the terrestrial environment and pollutes the aquatic environment, and it accumulates as a result of long-term degradation. During abiotic and biotic decomposition, harmful substances are released from landfill plastic that pollute the soil and water. Chlorinated plastics release toxic chemicals and pollute ecosystems, while the degradation of plastics in water releases chemicals such as polystyrene and Bisphenol A that pollute water Methane and CO_2 emissions during plastic microbial digestion contribute to global warming. Animals are exposed to plastic waste through ingestion and entanglement, with harmful consequences. Countries deal with plastic pollution by reducing waste, reducing production, recycling and alternatives (Reichert et al., 2020).

2.5 Possible solution for current food packaging material:

Growing environmental problems related to plastic have prompted research into alternative food packaging materials. Biodegradable materials such as biopolymers, bio-nanocomposites, bioplastics and edible coatings are being developed to replace plastics. Biodegradable polymers are renewable, nontoxic, biodegradable, biocompatible, reproducible, versatile, abundantly available, and have a low carbon footprint (Perera et al., 2022). However, problems such as viscosity, hydrophobicity, crystallization activity, brittleness, water sensitivity, thermal stability, gas-barrier properties, mechanical strength, processing difficulties and cost have prevented their widespread industrial adoption (Chaudhary et al., 2020).

To overcome these issues, biodegradable polymers can be mixed with other biodegradable polymers, compatibilizers (e.g., essential oils) and plasticizers (e.g., glycerol). Bioplastics are bio-based and/or biodegradable plastics that have similar properties to traditional plastics and offer additional benefits such as renewability and biodegradability (Perera et al., 2022).

Bio-nanocomposites consisting of a bio-based polymer matrix and an organic/inorganic filler with at least one nanoscale material are suitable as active and/or smart packaging materials due to their enhanced mechanical, thermal, barrier, antimicrobial and antioxidant properties. Functions. These materials focus on extending shelf life and reducing microbial growth in foods (Jeya Jeevahan et al., 2020).

2.6 Important properties of Biopolymers in food processing:

The properties of packaging materials, such as barrier, mechanical, chemical and thermal properties, are important to extend the shelf life of food and maintain its quality. The sealing properties of the biopolymer used in food packaging are the main parameter to extend the shelf life of the packaged food (Perera et al., 2022).

The gas permeability of the packaging material depends on the parameters; transmission, throughput and permeability. However, the barrier properties of materials depend not only on these factors but also on environmental conditions such as temperature, pressure, relative humidity and the nature of the packaged food. As a result, food packaging materials can extend the shelf life of foods by improving barrier properties (Rukmanikrishnan et al., 2020).

The oxygen barrier properties of the packaging material play an important role in the shelf life of fresh foods. Oxygen permeability is quantified by oxygen permeability percentage and oxygen permeability. It measures the amount of oxygen in the packaging system. As the oxygen permeability decreases, the oxygen pressure in the packaging system decreases, which increases the shelf life of the food (Rukmanikrishnan et al., 2020).

The water vapour barrier properties are significant for food products to maintain physical or chemical deterioration concerning the moisture content. The water vapour barrier properties are quantified by the water vapour permeability of the packaging material by the ASTM E-96-95 standard method and the water vapour transmission rate (Mathew et al., 2019). The water vapour permeability depends upon the solubility and the diffusion of the water in the polymer material. The shelf-life of some food products directly depends on the ratio of water exchange between the external and internal environment; thus, water transfer should be reduced to protect the food from moisture (Mohamed et al., 2020).

The mechanical properties of the packaging system are essential to protect food under stressful conditions such as storage, handling and processing of food. The architecture of the polymer matrix is a key factor that determines the mechanical properties of a biopolymer. The mechanical properties of the packaging material determine tensile properties such as tensile strength, elongation at break and modulus of elasticity (Perera et al., 2022).

Chemical resistance is important because the food in the packaging can be acidic and mixed with the packaging material. For safety reasons, it is important to find out what the food is chemically made of before packaging. When these chemicals combine with and are absorbed into the biopolymer matrix, the mechanical properties of the material may change. (Roy et al., 2019).

The thermal properties of the packaging material are determined by thermos-gravimetric and differential scanning calorimetry. Thermal properties and thermal stability are important for the heat resistance of the packaging material. Thus, these properties allow us to store and transport the food packaging at the temperature essential for the food products (Dong et al., 2021).

TABLE 3
ADVANTAGES AND DISADVANTAGES OF BIOPOLYMERS IN FOOD PROCESSING

Advantages	Disadvantages	References
Biodegradability: Biopolymers are environmentally friendly as they decompose naturally, reducing waste and pollution.	**Cost:** The production and processing of biopolymers can be more expensive than traditional plastics.	Reddy et al., 2013
Renewable Resources: Made from renewable resources such as plants and microorganisms, contributing to sustainability.	**Mechanical Properties:** Often have inferior mechanical properties compared to conventional plastics, such as lower strength and durability.	Averous and Pollet, 2012
Reduced Carbon Footprint: Lower carbon emissions during production compared to petroleum-based plastics.	**Water Sensitivity:** Many biopolymers are sensitive to moisture, which can affect their performance in food packaging.	Emadian et al., 2017
Safety: Generally recognized as safe for food contact and consumption, posing fewer health risks.	**Shelf Life:** Biopolymers may have shorter shelf lives and are more prone to degradation during storage.	Jamshidian et al., 2010
Functional Properties: Can offer specific functionalities such as edible coatings, antimicrobial properties, and oxygen barriers.	**Processing Challenges:** Require specialized equipment and processes for production and application.	Tang et al., 2012
Regulatory Support: Increasing governmental and regulatory support for biopolymer use in food packaging.	**Recycling and Disposal:** Limited recycling infrastructure and knowledge of proper disposal methods.	Brody et al., 2008

III. BIOSENSOR

In food processing and preservation, every step involved in handling, processing or production, storage as well as distribution affects the characteristics of the food, which may be undesirable or desirable. Hence, knowing the impact of every preservation technique and handling method on the food system is crucial in the food processing area which may result in food safety (Rahman, 2007). The safety monitoring as well as nutritional parameters of food is vital. The traditional analytical methods for safety and quality monitoring are tiresome, take much time and need well-trained operators, thus there is a necessity to produce rapid, sensitive as well as reliable methods to monitor food safety and quality rapidly. Therefore, biosensors can be a suitable substitute for traditional methods. Biosensor devices are the most relevant diagnostic methods for food (Shams et al., 2020).

A biosensor is described as a combined receptor transducer system, having the capability of giving discriminative semi-quantitative or quantitative analytical descriptions using a bio-recognition unit. It could be described as an "analytical system integrating a bio-substance, a bio-derived substance well linked with or within a physiochemical transducer, that could be thermometric, electrochemical, optical, magnetic or piezoelectric" (Anonymous[1], 2000).

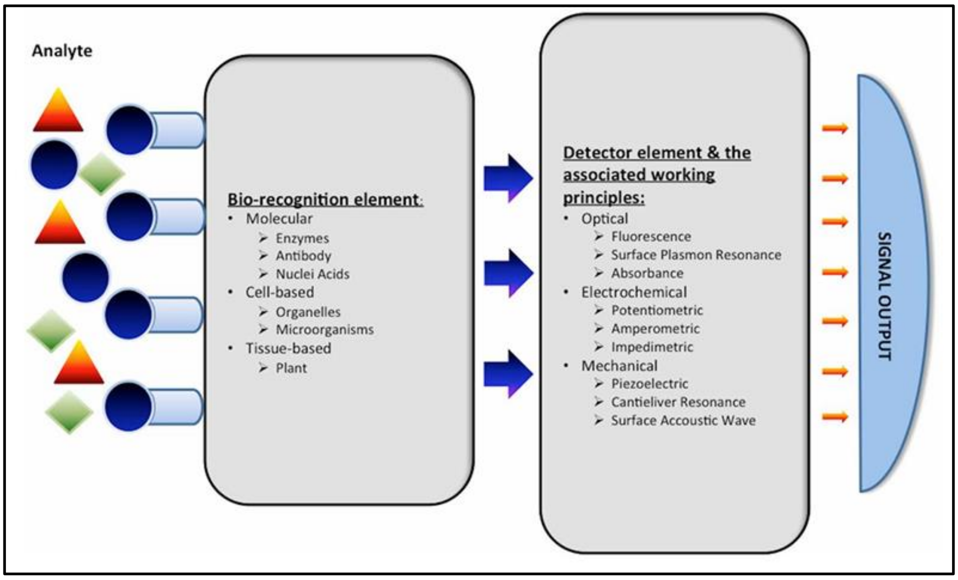


FIGURE 5: Schematic representation of a biosensor assembly (Lim and ahmed, 2024)

3.1 Generation of biosensor:

Depending upon their integration level biosensors are divided into three generations.

- **First generation:** In this generation, the biocatalyst is bound or trapped between the membranes which is then fixed to the transducer surface.
- **Second generation:** The instant covalent or adsorptive binding of the bioactive compound to the surface transducer allows the removal of the semi-permeable membrane.
- **Third generation:** The biocatalyst is bound to a piece of electric equipment that helps in transducing and amplifying the signal like the gate of a field effect transistor, which is essential for an additional miniaturization of nano-biosensors (Thakur and Ragavan, 2013).

3.2 Characteristics of biosensor:

To create a new and economically viable biosensor system, the following characteristics are crucial and must be taken into account.

- **Selectivity:** These devices must be extremely specific for the particular analyte and display less or no cross-reactivity with moieties possessing the same chemical composition.
- **Sensitivity:** These devices must have the ability to determine the variety of interest for an analyte requiring lesser further steps like pre-concentration or pre-cleaning of samples.
- **Linearity of response:** These systems should cover-up the concentration above which the specific analyte is intended to be identified.
- **Signal response reproducibility (SRR):** Whenever trial samples possessing similar amounts tend to be determined repeatedly, they must provide similar responses.
- **Recovery and quick response time:** These devices must have quick responses so that actual time monitoring of the particular analyte can be completed with efficacy. Also, the time of recovery must be little for the reusability of these devices
- **Operating life and stability:** The majority of the bio-materials are less stable under various environmental and biochemical environments. The bio-materials must be interfaced to maintain the activity for a longer time thus making these devices marketable and practically beneficial in the field (Arugula and Simonian, 2014).

3.3 Working principle of biosensor:

The basic principle of biosensor technology is to convert a biologically induced recognition event (*viz.*, enzyme, antibody) into a detectable signal, via a transducer and processor. The output is a display depicting both the presence and the concentration of the target analyte. The bio-receptor is a biomolecule that recognizes the target analyte (Meshram et al., 2018). A bio-receptor can be a tissue, microorganism, organelle, cell, enzyme, antibody, nucleic acid and biomimic. The transducer converts the recognition event into a measurable signal21Transduction may be optical, electrochemical, is thermometric, piezoelectric, magnetic and micro-mechanical, or combinations of one or more of the above techniques (Naik et al., 2017).

Biosensor = Bio-receptor + Transducer

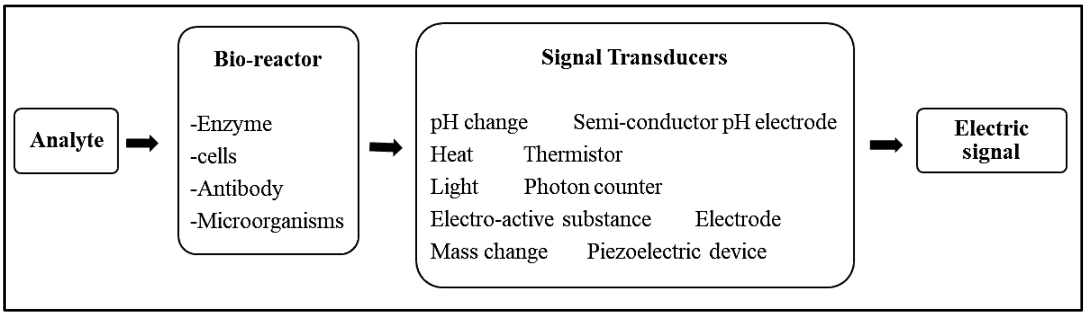


FIGURE 6: Principle of biosensors

Analytical chemistry plays an important role in food quality parameters, as almost all industries and public services depend on quality control. A food quality biosensor is a device that can respond to a food property or characteristics and transform the response(s) into a detectable, often electrical, signal. This signal may provide direct information about the quality factors being measured or may have a known relationship with the quality factor. The main immobilization methods, especially for enzymes, are physical adsorption, entrapment (using gels, polymers or inks), covalent binding or electrochemical polymerization and photo-polymerization. Physical adsorption is usually based on interactions between the biological element and the sensor, such as van der Waals forces (Shams et al., 2020).

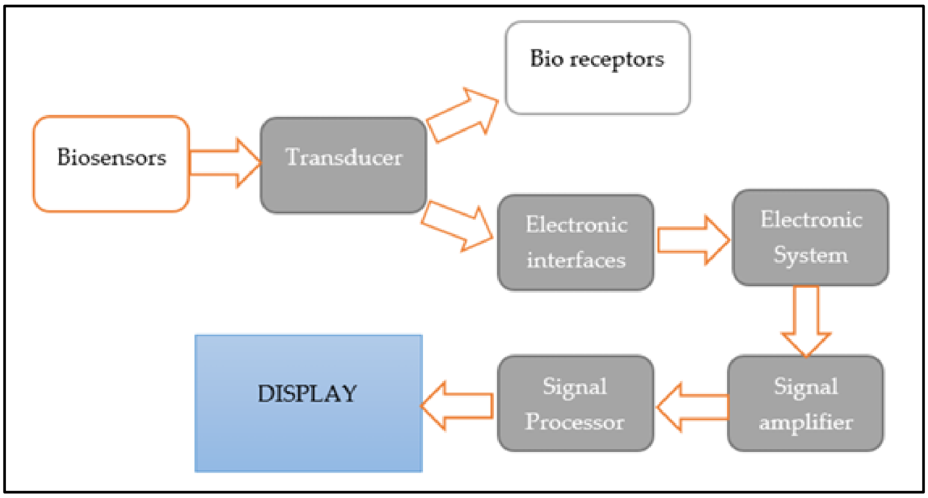


FIGURE 7: Operational mechanism of biosensors (Lee et al., 2015)

3.4 Types of biosensor

Biosensor types can be classified based on sensing elements or transducers. In the detection of foodborne pathogens, transducers play an important role.

3.4.1 Optical biosensors:

In the case of optical biosensors, the output signal measured is the emission of light, which allows direct (label-free) detection of food-borne pathogens. When cells bind to receptors or are immobilized on the surface of a sensor, these sensors can detect small changes. Optical diffraction and electrochemiluminescence are standard techniques for optical biosensors. Using the optical diffraction method, a silicon wafer is coated with proteins through covalent bonds and then exposed to ultraviolet light through a photomask. Under these conditions, antibodies exposed to ultraviolet light are inactivated. When the wafer is incubated with the antigen-antibody analyte, only the activated antibodies can bind to the antigen and signal under the laser light source. To improve sensitivity, this signal is measured directly or amplified (Yasmin et al., 2016).

Optical biosensors are classified into several subcategories such as reflection, refraction, resonance, dispersion, phosphorescence, infrared absorption, Raman scattering, fluorescence and chemiluminescence. Among them, surface plasmon resonance (SPR) and fluorescence-based optical biosensors are commonly used to detect foodborne pathogens due to their high sensitivity (Velusamy et al., 2010).

3.4.2 Electrochemical biosensors:

The basic principle of electrochemical biosensors is related to their ability to detect certain molecules. They are mainly used to detect DNA-binding drugs, glucose and hybridized DNA. In this technique, the electrons or ions to be measured are produced or suppressed by various chemical reactions. These biosensors are classified as amperometric, potentiometric or conductometric (Yasmin et al., 2016).

3.4.3 Mass-sensitive biosensors:

Mass-sensitive biosensors are used less often than optical and electrochemical biosensors. Also known as piezoelectric biosensors, they use piezoelectric crystals that are very sensitive and can detect small changes in mass. When a fixed-frequency alternating current is used, the piezoelectric crystals oscillate at a fixed frequency. This frequency depends on the mass of the crystal in addition to the fixed electrical frequency. The chemical reactions affect the frequency of oscillations, which is measured as an output signal (Velusamy et al., 2010).

3.5 Application of Biosensors in the food industry:

Food quality control is essential in the food industry; nowadays, efficient quality assurance is becoming increasingly important. Food producers gradually demand for effective quality control procedures to satisfy and regulate the requirements of consumers to enhance production feasibility, automation, quality sorting and decrease time and cost of production. Also, there is the requirement for rapid and efficient techniques to identify the allergens and pathogens present in the food product which can be fulfilled by the biosensors (Shams et al., 2020). Conventional methods for the detection of microbial contaminants are sensitive and inexpensive, but they require several days to yield results. In contrast, biosensors can rapidly relay results based on a progressive organic reaction. The biosensors play a vital role in the rapid and sensitive detection of foodborne (Yang et al., 2008).

Biosensors in the food industry are used for mainly two purposes. First is enzyme biosensor, which is mainly used in the liquor and beverages industry for detecting or measurement of carbohydrates from alcohol, amino acids, amines, amides, phenol etc. The second type of biosensor used in the food industry is for the detection of microorganisms. They are detected by two methods: Direct detection and indirect detection (Murugaboopathi et al., 2013).

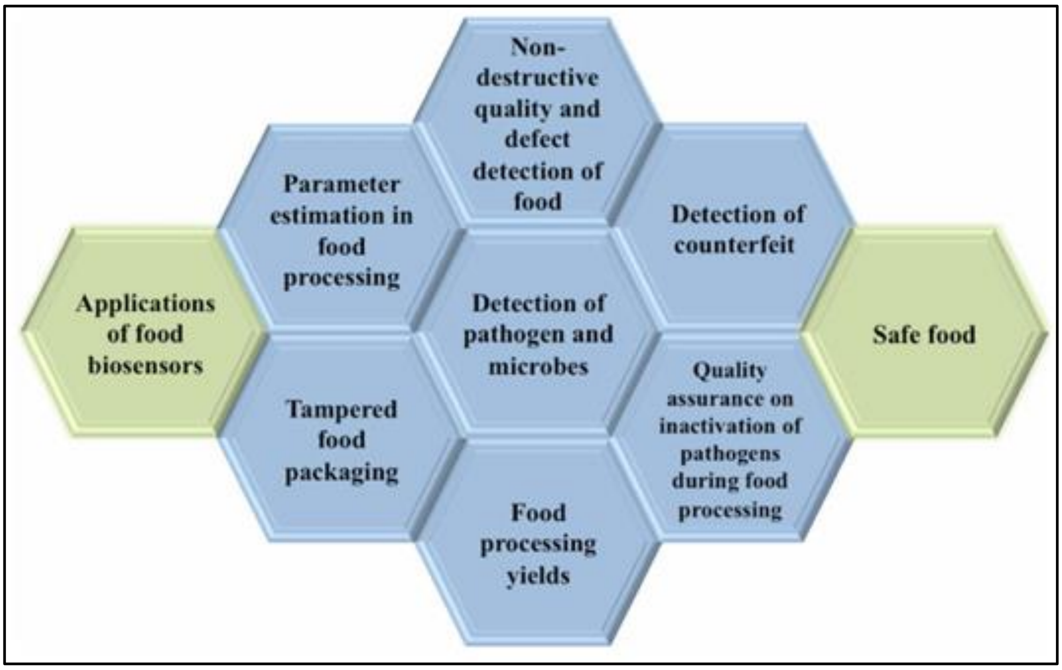


FIGURE 8: Various applications of food biosensors used in food industries

3.6 Important applications of biosensors in the food sector includes:

3.6.1 Safety of foods:

a. Xenobiotics such as additives, fertilizers, pesticides drugs, and other contaminations like: PCB's, dioxins, PAH's, bio-toxins and various heavy metals.

b. Bacterial toxins such as marine toxins, and mycotoxins.

c. Pathogens such as viruses, protozoa, and bacteria.

3.6.2 Food quality:

a. Food composition like amino acids, sugars, organic acids, alcohols, cholesterol

b. Shelf life: such as polyphenols and fatty acids (rancidity), biogenic amines (for freshness index), sugars and organic acids (maturation).

c. Ensures food safety in various fresh poultry, meat or fish.

d. Measures the concentration of organophosphate pesticides in dairy-based products such as milk.

Technological methods such as amino acids (fermentation), and sugars (pasteurization and fermentation). (Shams et al., 2020)

3.7 Future trends in Biopolymer/Biodegradable packaging:

Over the years, synthetic packaging materials have been the primary source of food packaging. However, the use of synthetic polymers presents challenges and limitations, mainly due to environmental pollution issues caused by plastics. In recent years, the trend to use biopolymers in food packaging has grown significantly. Their biodegradability, ecological friendliness, renewability, non-toxicity and lightness make them suitable for food packaging. However, the use of biopolymers in their pure form is limited due to their low mechanical, barrier and thermal properties. Furthermore, they are less cost-effective compared to synthetic polymers. The negative characteristics of biopolymers can be overcome by adding reinforcement agents such as nano-fillers and active agents. These reinforcing agents enhance the properties of the packaging materials, making them suitable for active and intelligent packaging materials by extending their shelf-life and improving the quality of packaged food products.

TABLE 4
FUTURE TRENDS IN BIOPOLYMER OR BIODEGRADABLE PACKAGING

Future trend	Description	References
Enhanced Performance	Development of biopolymers with improved mechanical and barrier properties to compete with conventional plastics.	Mohanty et al. (2018)
Cost Reduction	Innovations in production processes and economies of scale to reduce the cost of biopolymers.	Aeschelmann et al. (2016)
Smart Packaging (Active and Intelligent Packaging)	Integration of smart technologies such as sensors and indicators to monitor the freshness and quality of packaged products. Integration of active packaging (e.g., oxygen scavengers, antimicrobial agents) and intelligent packaging (e.g., sensors for real-time condition monitoring) to extend product shelf life and ensure quality	Ahmed et al. (2018)
Compostability and Biodegradability	The composting and biodegradation rates are enhanced to ensure complete breakdown in natural environments.	Tokiwa et al. (2009)
Functional Additives	Use of natural additives to improve properties such as antimicrobial activity, UV resistance, and shelf-life extension.	Arrieta et al. (2014)
Consumer Awareness	Growing consumer demand for sustainable packaging solutions driving the market for biopolymers.	Global Data (2020)

IV. SMART PACKAGING

Anything that offers “something extra” besides food containment and protection is considered smart food packaging. These “extras” can include anything from displays for monitoring pH, temperature, moisture, and freshness to a tracking device or extended shelf life. Smart packaging also analyses storage conditions, food quality, and the inside/outside environment of the package using a variety of sensors, indicators, and smart levels (Bhatlawande et al., 2023). Smart packaging such as active and intelligent packaging technologies, is considered as an innovative packaging technique for the development of a wide variety of products with competitive costs and achieved a great position in the preservation of different food systems. It is a fast-growing technology with a market demand projected to reach $28 billion by 2024, which will outgrowth superior market acceptance for a variety of product types (Bindu et al., 2023).

4.1 Active packaging:

Active packaging is an innovative concept that can be defined as a type of packaging that changes the condition of the packaging and maintains these conditions throughout the storage period to extend shelf-life or to improve safety or sensory properties while maintaining the quality of packaged food. Active packaging performs some desired role other than providing an inert barrier between the product and external conditions and combines advances in food technology, biotechnology, packaging and material science, to comply with consumer demands for ‘fresh-like’ products. This involves the incorporation of certain additives into the packaging film or within packaging containers to maintain and extend product shelf life. Active packaging technique is either scavenging or emitting systems added to emit (e.g., N_2, CO_2, ethanol, antimicrobials, antioxidants) and/or to remove (e.g., O_2, CO_2, odour, ethylene) gases during packaging, storage and distribution (Bindu et al., 2023).

4.2 Intelligent packaging:

Intelligent packaging detects certain characteristics of food it contains or the environmental conditions in which it is placed and notifies the people of the state of these properties. The attributes of intelligent packaging could be employed to check the efficiency and reliability of active packaging systems. Intelligent packaging has been described as packaging technology that can monitor the state of packaged foods to issue details about the quality of the packaged food during transport and storage. A variety of indicators such as temperature, time temperature, pack integrity, microbial growth, product authenticity and freshness are of interest to the fish packaging industry (Bindu et al., 2023).

TABLE 5
EXAMPLES OF ACTIVE AND INTELLIGENT PACKAGING SYSTEMS

Packaging system	Description	References
1) Active packaging		
Oxygen Scavengers	Absorb oxygen inside the packaging to prolong shelf life and prevent spoilage.	Brody et al., 2008
Moisture Absorbers	Absorb excess moisture to prevent mold growth and maintain product quality.	Yam et al., 2005
Ethylene Scavengers	Absorb ethylene gas to slow down ripening and extend the shelf life of fruits and vegetables.	Vermeiren et al., 1999
Antimicrobial Packaging	Incorporates antimicrobial agents to inhibit the growth of bacteria, fungi, and other microorganisms.	Quintavalla and Vicini, 2002
2) Intelligent packaging		
Temperature Indicators	Provide real-time information on the temperature history of the packaged product.	Kerry et al.,2006
Time-Temperature Indicators	Change colour based on the cumulative time-temperature exposure, indicating product freshness.	Mills, 2005
RFID Tags	Use radio frequency identification to track and monitor product information throughout the supply chain.	Espitia et al., 2012
Gas Indicators	Indicate the presence of gases like CO2 or O2, reflecting product status.	Mills, 2005

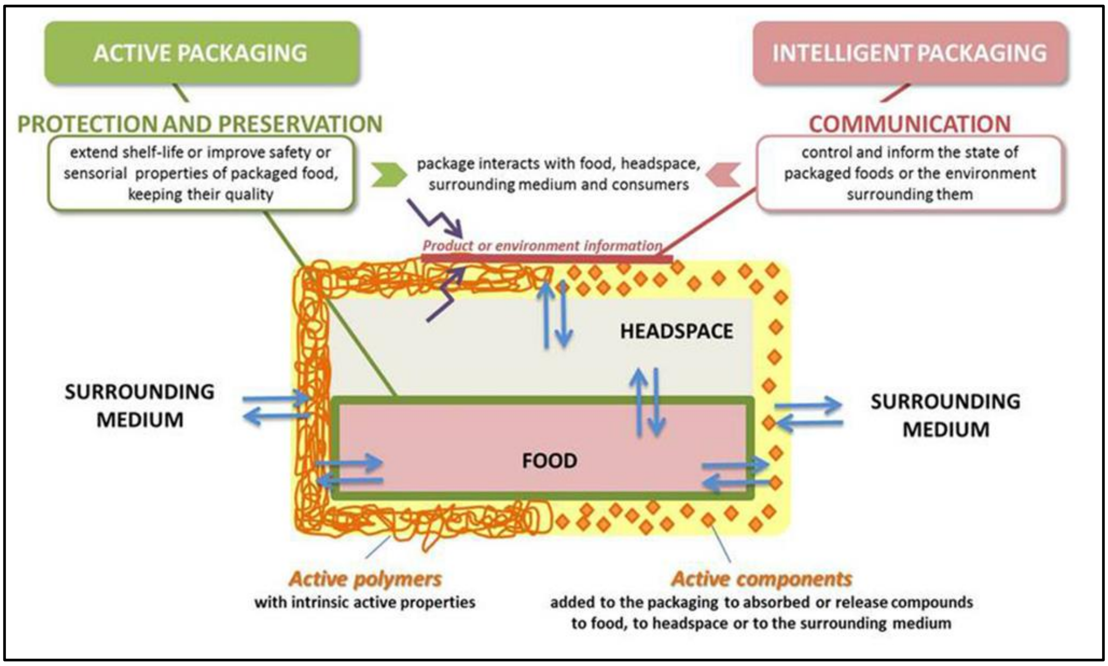


FIGURE 9: Schematic representation of active and intelligent packaging (Salgado et al., 2021)

V. CONCLUSION

In today's food industry, packaging is a foundation that performs several important tasks to maintain food quality, extend shelf life, and ensure consumer safety. New food packaging technologies seek to meet consumers' and industrial demands. The changes related to food production, sale practices, consumer lifestyles, environmental awareness, and the advances in new fields of knowledge such as biotechnology, act as driving forces to develop smart packages that can extend food shelf-life. The safety monitoring as well as nutritional parameters of food is vital. The traditional analytical methods for safety and quality monitoring are time-consuming and need well-trained operators, thus there is a necessity to produce rapid, sensitive as well as reliable methods to monitor food safety and quality rapidly. Also, food producers gradually demand effective quality control procedures to satisfy and regulate consumer requirements to enhance production feasibility, automation, quality sorting and decrease the time and cost of production. Biosensors can overcome all these disadvantages by offering quick, inexpensive and non-destructive procedures for quality control and pave the way for quick identification of food allergens, pathogens, and pesticide residues.

REFERENCES

[1] Alim A.A.A., Shirajuddin S.S.M. and Anuar F.H. (2022). A review of nonbiodegradable and biodegradable composites for food packaging application, *Journal of Chemistry*, Article 7670819.

[2] Anonymous[1] (2000). International Union of Pure and Applied Chemistry (IUPAC), USA.

[3] Anonymous[2] (2022). Global Packaging Market: Growth, Trends, COVID-19 Impact, and Forecasts (2022–2027). Mordor Intelligence LLP Publishers. https://www.reportlinker.com/p06246257/?utm_source=GNW

[4] Anonymous[3] (2022). Organisation for Economic Co-operation and Development (OECD). Plastic pollution is growing relentlessly as waste management and recycling fall short. https://www.oecd.org/environment/plastic-pollution-is growing-relentlessly-as-waste-management-and-recycling-fall-short.htm

[5] Arugula M. A. and Simonian A. (2014). Novel trends in affinity biosensors: current challenges and perspectives. *Measurement Science and Technology*. 25(3): 032001.

[6] Auras R., Harte B. and Selke S. (2004). An overview of polylactides as packaging materials. *Macromolecular Bioscience*, 4(9): 835-864. https://doi.org/10.1016/j.progpolymsci.2003.11.002

[7] Averous, L. and Pollet E. (2012). Environmental silicate nano-biocomposites. *Green Energy and Technology*. 13-39.

[8] Awulachew M. T. (2021). Food Additives and Food Processing Aids: The Role, Function And Future Research Need of Industrial Food Biotechnology. *International Journal of Medical Biotechnology and Genetics*. 8(11):73-82.

[9] Basavegowda N. and Baek K. H. (2021). Advances in Functional Biopolymer-Based Nanocomposites for Active Food Packaging Applications. *Polymers*. 13, 4198. https://doi.org/10.3390/ polym13234198

[10] Bastioli C. (2005). Handbook of biodegradable polymers. *Shawbury: Rapra Technology*.

[11] Bhatlawande A. R., Ghatge P. U., Shinde G. U., Anushree R. K. and Patil S. D. (2023). Unlocking the future of smart food packaging: biosensors, IoT, and nanomaterials. Food Science and Biotechnology https://doi.org/10.1007/s10068-023-01486-9

[12] Biotechnology. https://en.wikipedia.org/wiki/Biotechnology

[13] Brody A. L., Bugusu B., Han J. H., Sand C. K. and McHugh T. H. (2008). Innovative food packaging solutions. *Journal of Food Science*. 73(8): R107-R116.

[14] Caleb O. J. and Belay Z. A. (2023). Role of biotechnology in the advancement of biodegradable polymers and functionalized additives for food packaging systems. *Current Opinion in Biotechnology*. 83: 1-23. https://doi.org/10.1016/j.copbio.2023.102972

[15] Chaudhary P., Fatima F. and Kumar A. Relevance of Nanomaterials in Food Packaging and Its Advanced Future Prospects. Journal of Inorganic and Organometallic Polymers and Materials. 30: 5180-5192.

[16] Chen G. Q. (2010). Plastics completely synthesized by bacteria: Polyhydroxyalkanoates. *Microbiology*. 156(6): 1121-1131. https://doi.org/10.1016/j.micres.2009.05.001

[17] Draget K. I., Skjak-Bræk G. and Smidsrod O. (2005). Alginate-based new materials. *International Journal of Biological Macromolecules*, 16(6):375-380. https://doi.org/10.1016/j.foodhyd.2005.03.009

[18] Emadian S. M., Onay T. T. and Demirel B. (2017). Biodegradation of bioplastics in natural environments. *Waste Management*. 59: 526-536.

[19] Espitia P. J. P., Soares N. F. F., Coimbra J. S. D. R., Andrade N. J., Cruz R. S. and Medeiros, E. A. A. (2012). Zinc oxide nanoparticles: synthesis, antimicrobial activity and food packaging applications. *Food and Bioprocess Technology*. 5(5): 1447-1464.

[20] Evans, G. M. and Furlong, J. C. 2003. Environmental Biotechnology - Theory and Applications. John Willey and Sons Ltd.

[21] Folino A., Karageorgiou A., Calabro P. S. and Komilis D. (2020). Biodegradation of wasted bioplastics in natural and industrial environments: A review. *Sustainability*. 12, 6030.

[22] Garcia-Ochoa F., Santos V. E., Casas J. A. and Gomez E. (2000). Xanthan gum: Production, recovery, and properties. *Biotechnology Advances*, 18(7): 549-579. https://doi.org/10.1016/S0268-005X(99)00090-8

[23] Ghoshal G. (2018). palBiotechnology in food processing and preservation: An overview. *Advances in Biotechnology for Food Industry*. 27-54.

[24] Horst C., Pagno C. H., Flores S. H. and Costa T. M. H. (2020). Hybrid starch/silica films with improved mechanical properties. *Journal of Sol-Gel Science and Technology*. 95: 52–65.

[25] Ivankovic A., Zeljko K., Talic S., Bevanda A. M. and Lasic M. (2017). Biodegradable packaging in the food industry. *Journal of Food Safety and Food Quality*. 68(2): 26-38.

[26] J. Jacob, U. Lawal, S. Thomas, R.B. Valapa. (2020). Biobased polymer composite from poly(lactic acid): Processing, fabrication, and characterization for food packaging. pp. Y. Zhang (Ed.), Processing and Development of Polysaccharide-Based Biopolymers for Packaging Applications, Elsevier. 97-115.

[27] Jamshidian M., Tehrany E. A., Imran M., Jacquot M. and Desobry S. (2010). Poly-lactic acid: production, applications, nanocomposites, and release studies. *Comprehensive Reviews in Food Science and Food Safety*. 9(5): 552-571.

[28] Jendrossek D. (2009). Polyhydroxyalkanoate granules: biogenesis, structure, and potential use as natural smart materials. *Microbiological Monographs*. 14: 53-79.

[29] Jeya Jeevahan J., Chandrasekaran M., Venkatesan S. P., Sriram V., Britto Joseph G., Mageshwaran G. and Durairaj R. B. (2020). Scaling up difficulties and commercial aspects of edible films for food packaging: A review. Trends in Food Science and Technology. 100: 210-222.

[30] Kaplan D. L. (1998). Biopolymers from renewable resources. Springer Verlag: Berlin. 414.

[31] Karim A. A. and Bhat, R. (2009). Gelatin alternatives for the food industry: Recent developments, challenges and prospects. *Food Hydrocolloids*. 23(3):563-576. https://doi.org/10.1016/j.foodhyd.2009.01.001

[32] Kerry J. P. (2012). "Application of smart packaging systems for conventionally packaged muscle-based food products," in Advances in Meat, Poultry and Seafood Packaging, ed J. P. Kerry (Ireland: Woodhead Publishing), 522–564.

[33] Kerry J. P., O'Grady M. N. and Hogan S. A. (2006). Past, current and potential utilisation of active and intelligent packaging systems for meat and muscle-based products: a review. *Meat Science*. 74(1): 113-130.

[34] Lee S.Y., Lee S.J., Choi D.S. and Hur S.J. (2015). Current Topics in Active and Intelligent Food Packaging for Preservation of Fresh Foods. *Journal of The Science of Food and Agriculture.* 95: 2799-2810.

[35] Lim S. A. and Ahmed M. U. (2024). Introduction to Food Biosensors. Book chapter, 1-21. http://books.rsc.org/books/edited-volume/chapter-pdf/1537977/bk9781782623618-00001.pdf

[36] Lynd L. R., Weimer P. J., van Zyl W. H. and Pretorius I. S. (2002). Microbial cellulose utilization: fundamentals and biotechnology. *Microbiology and Molecular Biology Reviews*. 66(3): 506-577.

[37] Marangoni Júnior L., Coltro L., Dantas F. B. H. and Vieira R. P. (2022). Research on Food Packaging and Storage. 12, 1714. https://doi.org/10.3390/ coatings12111714

[38] Mathew S., Snigdha S., Mathew J. and Radhakrishnan E.K. (2019). Biodegradable and active nanocomposite pouches reinforced with silver nanoparticles for improved packaging of chicken sausages. *Food Packaging and Shelf Life*. 19: 155-166.

[39] Matthews S., Li X.-y., Guo P., Chen Y. and Li H.-j. (2021). Preparation and characterization of PCL-grafted zein film via atmospheric-pressure cold plasma pretreatment. Plasma Process. *Polymers*.

[40] Meshram B. D., Agrawal A. K., Adil S., Ranvir S. and Sande K. K. (2018). Biosensor and its Application in Food and Dairy Industry: A Review. *International Journal of Current Microbiology and Applied Sciences*. 7(2): 3305-3324.

[41] Mills A. (2005). Oxygen indicators and intelligent inks for packaging food. *Chemical Society Reviews*. 34(12): 1003-1011.

[42] Mohamed S.A.A., El-Sakhawy M. and El-Sakhawy M.A.M. (2020). Polysaccharides, Protein and Lipid-Based Natural Edible Films in Food Packaging: A Review. Carbohydrate Polymers. 2020, 238, 116178.

[43] Mostafavi F. S. and Zaeim D. (2020). Agar-based edible films for food packaging applications review. *International Journal of Biological Macromolecules*. 159: 1165-1176.

[44] Murugaboopathi G., Parthasarathy V., Chellaram C., Prem Anand T. and Vinurajkumar S. (2013). Applications of Biosensors in Food Industry. Biosciences Biotechnology Research. 10(2): 711-714.

[45] Naik K.M., Srinivas D., Sasi B. and Basha S.K.J. (2017). Biosensors in Food Processing - A Review. *Int. J. Pure App. Biosci*. 5(4): 1219-1227 (2017). doi: http://dx.doi.org/10.18782/2320-7051.5546

[46] Necas J. and Bartosikova L. (2013). Carrageenan: A review. *Veterinary Medicine*. 58(4): 187-205. https://doi.org/10.1016/j.carbpol.2013.03.025

[47] Pawar P. A. and Purwar A. H. (2013). Biodegradable polymers in food packaging. *American Journal of Engineering Research*. 2(5): 151-164.

[48] Perera K. Y., Jaiswal A.K. and Jaiswal S. (2023). Biopolymer-Based Sustainable Food Packaging Materials: Challenges, Solutions, and Applications. *Foods*. 12, 2422. https://doi.org/10.3390/ foods12122422

[49] Quintavalla S. and Vicini L. (2002). Antimicrobial food packaging in meat industry. *Meat Science*. 62(3): 373-380.

[50] Rahman, M. S. 2007. Handbook of food preservation. (2nd Ed.). CRC press.

[51] Ranjha M.M.A.N., Shafique B., Khalid W. (2022). Applications of Biotechnology in Food and Agriculture: a Mini-Review. Proceedings of the National Academy of Sciences, India Section B: Biological Sciences. 92, 11-15 (2022). https://doi.org/10.1007/s40011-021-01320-4

[52] Ravi Kumar M. N. V. (2000). A review of chitin and chitosan applications. *Reactive and Functional Polymers*. 46(1): 1-27. https://doi.org/10.1016/S0144-8617(00)00119-9

[53] Reddy R. L., Reddy V. S. and Gupta G. A. (2013). Study on biodegradable polymers and their applications. *International Journal of Environmental Science and Development*. 4(2): 77-81.

[54] Reichert C. L., Bugnicourt E., Coltelli M. B., Cinelli P., Lazzeri A., Canesi I., Braca F., Martinez B. M., Alonso R. and Agostinis L.

(2020). Bio-Based Packaging: Materials, Modifications, Industrial Applications and Sustainability. *Polymers*. 12, 1558.

[55] Rinaudo M. (2006). Chitin and chitosan: Properties and applications. *Progress in Polymer Science*. 31(7): 603-632.

[56] Rodrigues C., Souza V. G. L., Coelhoso I. and Fernando A. L. (2021). Bio-Based Sensors for Smart Food Packaging - Current Applications and Future Trends. Sensors. 21, 2148. https://doi.org/10.3390/ s21062148

[57] Roy S., Rhim, J. W. and Jaiswal L. (2019). Bioactive agar-based functional composite film incorporated with copper sulfide nanoparticles. Food Hydrocolloids. 93: 156-166.

[58] Rukmanikrishnan B., Ramalingam S., Rajasekharan S.K. and Lee J. (2020). Binary and ternary sustainable composites of gellan gum, hydroxyethyl cellulose and lignin for food packaging applications: Biocompatibility, antioxidant activity, UV and water barrier properties. International Journal of Biological Macromolecules. 153: 55-62.

[59] Salgado P. R., Di Giorgio L., Musso Y. S. and Mauri A. N (2021) Recent Developments in Smart Food Packaging Focused on Biobased and Biodegradable Polymers. Frontiers in Sustainable Food Systems. 5:630393. doi: 10.3389/fsufs.2021.630393

[60] Shams R., Singh J., Ashraf S., Manzoor M. and Dar A.H. (2020). Application of biosensors in food quality control. *Journal of Postharvest Technology*. 8(1): 53-74.

[61] Singh R. S., Saini G. K. and Kennedy J. F. (2008). Pullulan: Microbial sources, production and applications. *Carbohydrate Polymers*, 73(4): 515-531. https://doi.org/10.1016/j.foodchem.2008.07.045

[62] Siracusa V., Rocculi P., Romani, S. and Dalla Rosa, M. (2008). Biodegradable polymers for food packaging: a review. *Trends in Food Science and Technology*. 19(12): 634-643.

[63] Tako M., Raksakulthai N., Kanatt S. R. and Jantasee, S. (2020). Potential applications of polysaccharide-based biopolymers in food packaging. *Carbohydrate Polymers*, 230, 115600. https://doi.org/10.1016/j.carbpol.2019.115600

[64] Tang X., Alavi S. and Herald T. J. (2012). Barrier and mechanical properties of starch-clay nanocomposite films. *Cereal Chemistry*. 89(5): 472-477.

[65] Thakur M. S. and Ragavan K. V. (2013). Biosensors in food processing. *Journal of Food Science and Technology*. 50(4): 625 641.

[66] Tokiwa Y. and Calabia B. P. (2006). Biodegradability and biodegradation of poly(lactide). *Applied Microbiology and Biotechnology*. 72(2): 244-251.

[67] Upadhye M. C., Kuchekar M. C., Pujari R. R. and Sable N. U. (2022). Biopolymers: A comprehensive review. *Open Access Research Journal of Science and Technology*. 04(01): 13–18.

[68] Velusamy V., Arshak K., Korostynska O., Oliwa K. and Adley C. (2010). An overview of foodborne pathogen detection: In the perspective of biosensors. *Biotechnology advances*. 28(2):232-254.

[69] Vermeiren L., Devlieghere F., van Beest M., de Kruijf N. and Debevere J. (1999). Developments in the active packaging of foods. *Trends in Food Science and Technology*. 10(3), 77-86.

[70] Voragen A. G. J., Coenen G.-J., Verhoef R. P. and Schols H. A. (2009). Pectin, a versatile polysaccharide presents in plant cell walls. *Carbohydrate Polymers*. 79(1):101-111. https://doi.org/10.1016/j.carbpol.2009.09.024

[71] Yam K. L., Takhistov P. T. and Miltz J. (2005). Intelligent packaging: concepts and applications. Journal of Food Science, 70(1), R1-R10.

[72] Yang H., Li H. and Jiang X. (2008). Detection of foodborne pathogens using bio-conjugated nanomaterials. *Microfluidics and Nanofluidics*. 5(5):571-583.

[73] Yasmin J., Ahmed M. R. and Cho B. (2016). Biosensors and their Applications in Food Safety: A Review. *Journal of Biosystems Engineering*. 41(3): 240-254.

[74] Yoshida S., Hiraga K., Takehana T., Taniguchi I., Yamaji H., Maeda Y. and Oda K. (2016). A bacterium that degrades and assimilates poly(ethylene terephthalate). *Science*. 351(6278): 1196-1199.

[75] Yu P. (2017). Food Biotechnology-An Important and Promising Research Field. *Journal of Food Biotechnological Research*. 1(1):1.

Assessing the Role of Determinants on Consumer's Purchase Intention and Consumption of Branded Bread in an Academic Environment

Sushil Kumar[1]; Hena Imtiyaz[2]*

[1]Research Scholar, Department of Processing and Food Engineering, Sam Higginbottom University of Agriculture, Technology and Sciences, Prayagraj – 211007 Uttar Pradesh India,
[*2]Assistant Professor, Department of Processing and Food Engineering, Sam Higginbottom University of Agriculture, Technology and Sciences, Prayagraj – 211007 Uttar Pradesh India.
*Corresponding Author

Received:- 08 April 2025/ Revised:- 15 April 2025/ Accepted:- 25 April 2025/ Published: 30-04-2025

Abstract— *The present research aims to investigate the role of convenience orientation, time scarcity, cooking skills, sensory appeal, nutritional quality, safety consciousness, health consciousness, perceived price, product information, processing technology and packaging quality on purchase intention and consumption of branded bread. A structured questionnaire was used to collect data from 500 consumers across four universities of Haryana, India. Confirmatory factor analysis and structural equation modeling were used to analyse the data. The factor loading, cronbach's alpha, composite reliability, average variance extracted and correlations estimates demonstrate good internal consistency and reliability of questionnaire as well as convergent and discriminant validity of measurement model. The model fit indices demonstrate good fit of measurement and structural models. The path analysis of structural model reveal that convenience orientation (ß=0.84); sensory appeal (ß=0.73); nutritional quality (ß=0.69); safety consciousness (ß=0.70); health consciousness (ß=0.82); perceived price (ß=0.61); time scarcity (ß=0.75); lack of cooking skills (ß=0.59); packaging quality (ß=0.77); product information (ß=0.86); and processing technology (ß=0.81) were positively related with purchase intention and consumption of branded bread. Convenience orientation, health consciousness, processing technology and product information/labeling were the key determinants influencing consumer's purchase intention and consumption of branded bread in an academic environment.*

Keywords— Branded bread; determinants; purchase intention; consumption; SEM.

I. INTRODUCTION

The demand for bakery products is rising, due to convenience and nutritional benefits. Bread is considered as a convenience food, which requires minimum time and culinary knowledge to prepare and consume. New low-carb, high-fibre, multigrain and fortified bread that appeal to health-conscious consumers has triggered the market growth. Global bread market is estimated to register a compound annual growth rate (CAGR) of 1.43% during 2019-2024. The European bakery products market is expected to grow at a CAGR of 3.12% during the forecast period of 2020 - 2025. Europe holds the largest share in the global bread market, by volume United States retail packaged bread market size was valued at over USD 20 billion in 2018 and is expected to register over 2.5% CAGR from 2019 to 2026. The Asia-Pacific bakery products market is estimated to record a CAGR of 8.46% during the forecast period of 2022-2027. Indian bakery market is estimated to grow at a CAGR of 8.5% between 2021 and 2026 to reach a value of USD 12.39 billion by 2026. Indian bread market is projected to grow at CAGR of 10% and reach nearly $ 1.4 billion by 2026 on an account of rising awareness about healthy lifestyle and wellness, increasing disposable income, busy lifestyle and changing eating habits of the consumers across the country (Research and Market 2020).

The convenience orientation is important determinant, which drives consumer towards shopping and consumption of branded bread. The significant increase of female employment, rise in nuclear families, busy work schedule, desire to maximize social and leisure time, long working hours, career-oriented lifestyle and multiple responsibilities are the most important factors influencing convenience food choice (Hena *et al.*, 2021a; Hena *et al.*, 2021b; Hena *et al.*, 2022a; Hena *et al.*, 2022b; Hena *et* *al.*, 2023). Time scarcity, induced by various factors results in the modification of food consumption behavior (Contoni *et al.*, 2018; Hena *et al.*, 2023). Cooking skills and motivation is important to provide nutritive and balanced diet for a healthy lifestyle. In both developed and emerging economies, cooking skills and motivation are diminishing fast due to lack of training from parents, and busy lifestyle. Irrespective of gender, cooking is perceived as a difficult and low priority task (Priyadarshini, 2015; Djupegot *et al.*, 2017; Hena *et al.*, 2023).

Sensory characteristics such as taste, appearance, freshness, texture, color, and smell are important motivating factors, driving consumers towards shopping and consumption of branded bread. Due to advances in food processing and packaging technology, the sensory appeal of convenience food products has been considerably improved in recent years. The sensory appeals undoubtedly are believed to influence consumers' perception, purchase intention and consumption of convenience food products significantly (Dewettinck *et al.*, 2008; Tikkanen and Vääriskoski, 2010; Lakshmi, 2016; Skorepa and Picha, 2016; Jadhav and Chavan, 2019; Khannal, 2020; Hena *et al.*, 2021a, Compaore-Sereme *et al.*, 2023). Nutritional quality is another most important determinant, which motivates and drives consumers towards convenience food choice as well as being directly linked with perception, purchase decision, and consumption. Nutritional quality such as nutritional value, natural ingredients, protein, fiber, vitamin, mineral and quality certification are the important factors, which drive consumers towards purchase intention and consumption of convenience food products like bread (Tikkanen and Vääriskoski, 2010; Moslehpour *et al.*, 2015; Cecilia *et al.*, 2016; Hena *et al.*, 2021a; Lădaru *et al.*, 2021).

Food safety is another important determinant that influences the shopping and consumption of branded bread. The safety attributes such as additives, pesticides, hormones, artificial ingredients, and safety certification are important attributes of food safety. Food safety is one of the most influential factor in context of shopping and consumption of food products (Olusegun *et al.*, 2015; Hena *et al.*, 2021a). Health is the prime concern of consumers while purchasing and consuming convenience food such as branded bread. Health is a multidimensional construct that embodies overall wellbeing of consumers regarding physical, mental, and social aspects. Health-related issues such as calories, fat, salt, sugar, and balanced diet play important roles in influencing consumers for purchase and consumption of processed food products (Musaiger, 2014; Cecilia *et al.*, 2016; Contini *et al.*, 2018; Sajdakowska *et al.*, 2019; Engindeniz *et al.*, 2021; Hena *et al.*, 2021a; Wambugu and Musyoka, 2022).

Food price, family income, disposable income, and availability are the major economic drivers influencing shopping and eating of bakery products. Changing lifestyle, employment status, dual income, availability of the product choice and entry of multinational companies in bakery sector are the most important drivers influencing consumer's choice for branded bread in India (Tikkanen and Vääriskoski, 2010; Skorepa and Picha, 2016; Engindeniz *et al.*, 2021; Lădaru *et al.*, 2021; Al Togar and Al Hakim, 2022). Product information, sensory, nutritional facts, certification, quality, health, cooking instructions, place of origin and price are important attributes of food labeling / product information that attract and motivate consumers towards shopping and consumption of food products (Grujic *et al.*, 2013). Food processing technology plays an important role in improving and maintaining sensory, quality, safety and health attributes as well as the acceptability of food products (Ojha *et al.*, 2015; Misra *et al.*, 2017; Hena *et al.*, 2022a).

Bakery product is one of the fastest growing sectors in the Indian economy. Demand for branded bread is increasing significantly in India, particularly in urban areas, owing to a busy lifestyle, lack of cooking skills and motivation, higher disposable income, career-oriented work commitments, a significant increase in dual working families, desire for more leisure time, and a significant change in food-related lifestyle. Despite the significant market expansion and economic relevance of bakery products in India, no comprehensive research has been conducted to examine the impact of determinants influencing consumer's purchase and consumption of branded bread. Therefore the main objective of this study was to understand the role of convenience orientation, time scarcity, cooking skills, sensory appeal, nutritional quality, safety consciousness, health consciousness, perceived price, product information, processing technology and packaging quality on purchase intention and consumption of branded bread in an academic environment.

1.1 Theoretical background and development of hypotheses:

1.1.1 Convenience orientation:

The convenience orientation induced by multiple factors is a key determinant, influencing consumer purchase intention and consumption of branded bread. The significant increase of female employment, significant rise in expendable income, diminishing trend of cooking skill and motivation, multiple responsibilities, busy work schedule, and competitive environment significantly increased the demand and consumption of convenience food (Olusegun *et al.*, 2015; Contini *et al.*, 2018; Hena *et al.*, 2021b). Considering the aforementioned research findings, the following hypothesis is proposed:

H 1: Convenience orientation is positively related to purchase intension of branded bread.

1.1.2 Time scarcity:

Time scarcity, induced by various factors results in the modification of food consumption behaviour such as significant increase in convenience food consumption and reduction in home cooked food. Long and erratic working hours, significant increase in women's employment, desire for more time on leisure activities, decreasing in joint family system; employment status, significant increase in dual working nuclear families and work pressure are the major factors resulting to time scarcity that drive consumers towards convenience food choice (Cecilia *et al.*, 2016; Hena *et al.*, 2023). In light of the above-mentioned findings, the following hypothesis is formulated:

H 2: Time scarcity is positively related to purchase intension of branded bread.

1.1.3 Cooking skills:

Cooking skills, knowledge and motivation are eroding in both developed and emerging economies due to significant changes in lifestyle, reluctant to pass cooking skills to daughter due to inclination towards professional career, desire to maximize leisure time, time pressure due to multiple responsibilities and lack of provision for imparting culinary skills in schools/ colleges / universities (Hartmenn *et al.*, 2013; Priyadarshini, 2015; Contini *et al.*, 2018; Sajdakowska *et al.*, 2020; Hena *et al.*, 2023). The lack of cooking skills, knowledge and motivation are important, factors in motivating and driving consumers towards choice of convenience food such as branded bread. Considering the aforementioned research findings, the following hypothesis is postulated:

H 3: Lack of cooking skills is positively related to purchase intension of branded bread.

1.1.4 Sensory appeal:

The sensory characteristics such as taste (Heenan *et al.*, 2009; Jadhav and Chavan, 2019; Sajdakowska *et al.*, 2020; Hena *et al.*, 2021a); flavour (Braghieri *et al.*, 2016; Hena *et al.*, 2021a); appearance (Heenan *et al.*, 2009; Tikkanen and Vääriskoski, 2010; Skorepa and Picha, 2016; Hena *et al.*, 2021a); freshness (Heenan *et al.*, 2009; Skorepa and Picha, 2016); texture (Braghieri *et al.*, 2016; Hena *et al.*, 2021a); overall liking (Braghieri *et al.*, 2016) and smell (Sajdakowska *et al.*, 2020; Hena *et al.*, 2021a) are the important motivating factors, driving consumers towards shopping and consumption of convenience food such as branded bread. Considering the aforementioned research findings, the following hypothesis is developed:

H 4: Sensory appeal is positively related to purchase intension of branded bread.

1.1.5 Nutritional quality:

The nutritional quality of convenience food such as bread play important role in motivating and driving consumers towards its purchase and consumption (Dewettinck *et al.*, 2008; Grujic *et al.*, 2013; Moslehpur *et al.*, 2015; Di Vita *et al.*, 2019; Khanal, 2020; Hena *et al.*, 2021a; Lădaru *et al.*, 2021). The food quality certification from authorized agencies and brand provide the details of production process, ingredients, nutritional facts, shelf life, cooking instruction, place of production, safety, environment and ethical issues to consumers are the core aspects of integrated food quality concept (Hena *et al.*, 2021a). Mascarello *et al.* (2015) reported that the perception regarding the nutritional quality of food products considerably influenced the purchase decision and consumption behavior of consumers. Based on the comprehensive literature review, the following hypothesis is proposed:

H 5: Nutritional quality is positively related to purchase intension of branded bread.

1.1.6 Safety consciousness:

Food safety is another important determinant influences the shopping and consumption of processed food such as branded bread (Olusegun *et al.*, 2015). The primary concerns of consumers about food safety are additives (Hena *et al.*, 2021a), pesticides (Omari and Frempong, 2015; Hena *et al.*, 2021a), hormones (Hena *et al.*, 2021a), artificial ingredients (Omari and Frempong, 2015; Hena *et al.*, 2021a), color (Omari and Frempong, 2015; Hena *et al.*, 2021a) which in turn significantly influenced consumer’s purchase intention and consumption of processed food such as branded bread. Based on the aforementioned research findings, the following hypothesis is proposed:

H 6: Safety consciousness is positively related to purchase intention of branded bread.

1.1.7 Health consciousness:

Health benefit is most important determinant, which motivate and drive consumer's for purchase and consumption of bread (Dewettinck *et al.*, 2008; Sajdakowska *et al.*, 2020; Engindeniz *et al.*, 2021; Wambugu and Musyoka, 2022). Health-related issues such as calories (Musaiger, 2014; Hena *et al.*, 2021a), fat (Musaiger, 2014; Hena *et al.*, 2021a), salt (Cecilia *et al.*, 2016; Hena *et al.*, 2021a), sugar (Cecilia *et al.*, 2016; Hena *et al.*, 2021a) and balanced diet (Contini *et al.*, 2018; Hena *et al.*, 2021a) play important roles in influencing consumer's for purchase and consumption of convenience food such as branded bread. Hoek *et al.* (2017) stated that the government regulatory authorities, responsible for the formulation of food laws and regulations, should prioritize health-related attributes of convenience food. Based on the aforementioned research findings, the following hypothesis is proposed:

H 7: Health consciousness is positively related to purchase intention of branded bread.

1.1.8 Perceived price:

Family income, disposable income, food price and availability are the major economic drivers influencing shopping and consumption of bakery products. Changing lifestyle, employment status, dual income, availability of the product choice, competitive price and entry of multinational companies in bakery sector are the most important drivers influencing consumers purchase decision and consumption of branded bread (Tikkanen and Vääriskoski, 2010; Nagyová *et al.* 2014; Skorepa and Picha, 2016; Lădaru *et al.*, 2021; Engindeniz *et al.*, 2021; Al Togar and Al Hakim, 2022). The convenience orientation, cooking skills, processing technology, sensory appeal, nutritional quality, safety consciousness, health consciousness and food price are important determinants which influenced consumer's food choice (Hena *et al.*, 2021a; Hena *et al.*, 2021b; Hena *et al.*, 2022a; Hena *et al.*, 2022b; Hena *et al.*, 2023). Based on the aforementioned research findings, the following hypothesis is proposed:

H 8: Perceived price is positively related to purchase intention of branded bread.

1.1.9 Product information:

Sensory, nutritional facts, certification, quality, safety, health, cooking instructions, place of origin and price are important attributes of food product information / labeling that attract and motivate consumers towards shopping and consumption of convenience food such as bread (Vlaeminck *et al.*, 2014; Hena *et al.*, 2022a). Grujic *et al.* (2013) reported that it is necessary to inform and educate consumers regarding food quality, safety and labeling. Mhurchu *et al.* (2018) stated that the product information had positive impact on the purchase of healthier food. In light of the aforementioned research findings, the following hypothesis is proposed.

H 9: Product information is positively related to purchase intention of branded bread.

1.1.10 Processing technology:

The consumers perceived that advanced and novel food processing technologies improve sensory appeal, nutritional quality, safety attributes, healthiness and shelf life of processed food products. Advanced food processing technologies such as HPP and PEF maintained naturalness, improved sensory, quality and shelf life of processed food products (Ojha *et al.*, 2015; Misra *et al.*, 2017; Hena *et al.*, 2022a). In light of the aforementioned research findings, the following hypothesis is proposed:

H 10: Novel food processing technology is positively related to purchase intention of branded bread.

1.1.11 Packaging quality:

Packaging characteristics is an important determinant which motivates and drives consumers towards convenience food choice, like branded bread (Tikkanen and Vääriskoski, 2010; Wyrwa and Barske, 2017; Majid *et al.*, 2018; Jadhav and Chavan, 2019; Hena *et al.*, 2022a). Packaging attributes includes colour, shape, size, functional attributes, durability, informational attributes, logo, brand name, and product information. Jadhav and Chavan (2019) reported that product and brand recognition, affordability, availability and packaging were the important factors that influence the preference of bakery products like bread. In light of the aforementioned research findings, the following hypothesis is proposed:

H 11: Packaging quality is positively related to purchase intention of branded bread.

1.1.12 Purchase intention and consumption:

The consumer's purchase intention and consumption of convenience food such as branded bread is complex process and governed by socio demographics, physical, economic, psychological, marketing, commercial, ethical and religious determinants (Priyadarshini, 2015; Bandara *et al.*, 2016; Hena *et al.*, 2021a; Hena *et al.*, 2021b; Hena *et al.*, 2022a; Hena *et al.*, 2022b; Hena *et al.*, 2023). Based on the aforementioned research findings, the following hypothesis is proposed:

H 12: Purchase intention of branded bread is positively related to consumption of branded bread.

The conceptual model for the present study is based on aforementioned research findings to assess the role of convenience orientation, time scarcity, cooking skills, sensory appeal, nutritional quality, safety consciousness, health consciousness, perceived price, product information, processing technology and packaging quality influencing purchase intention and consumption of branded bread (Figure 1).

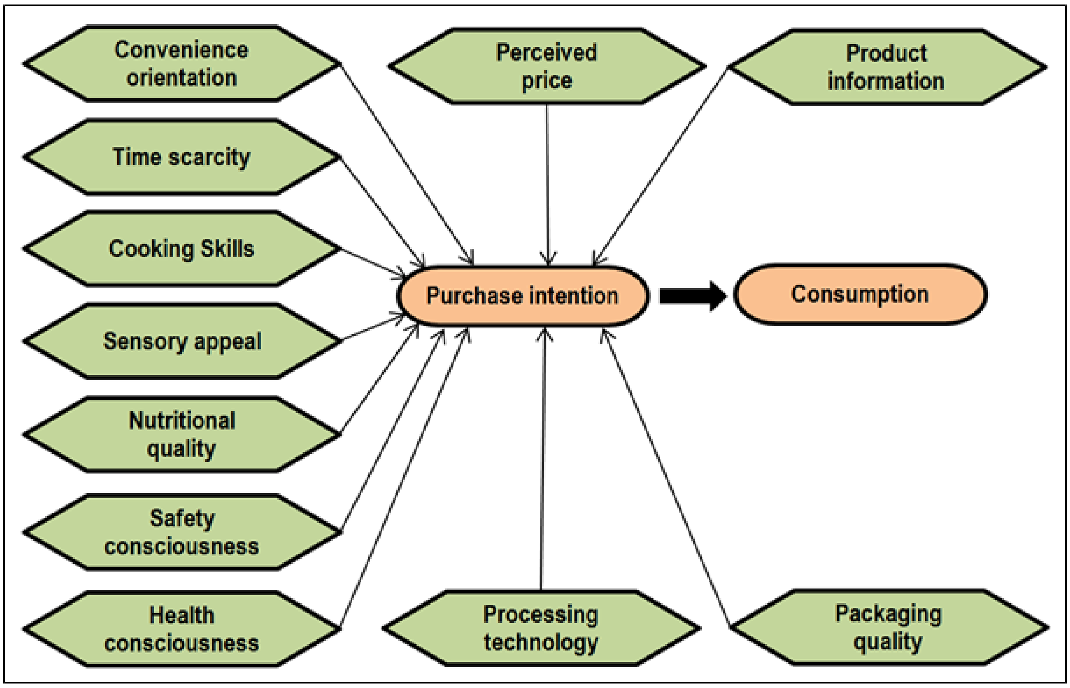


FIGURE 1: Conceptual Model

II. MATERIALS AND METHODS

2.1 Description of study area:

The present study was carried out in North India i.e. Hisar, Haryana (29.9' N 75.43' E; 215m above sea level) to examine the role of determinants influencing purchase intention and consumption of branded bread. Hisar is one of the fast growing cities of the Northern India. In summer, day temperatures ranges from 40 to 46°C, whereas winter day temperature ranges from 1.5°C to 4°C. The annual rainfall is approximately 450 mm. Total population of Hisar is approx. 1.743 million with 44% females and 56% males and having literacy rate of 81.04%. Hisar comprised of four universities and 10 colleges with a large chunk of students and in service personnel who prefer branded bread.

2.2 Development and pre-testing of questionnaire:

The questionnaire was developed to examine the role of convenience orientation, time scarcity, cooking skills, sensory appeal, nutritional quality, safety consciousness, health consciousness, perceived price, product information, processing technology and packaging quality on purchase intention and consumption of branded bread. The questionnaire was pre-tested at Haryana Agricultural University, Hisar, India. After completing the questionnaire, the participants were requested to provide their feedback regarding design, structure and interpretation of the questionnaire to examine the role of convenience orientation, time scarcity, cooking skills, sensory appeal, nutritional quality, safety consciousness, health consciousness, perceived price, product information, processing technology and packaging quality on purchase intention and consumption of branded bread. The feedback obtained from participants / consumers were included in final questionnaire (Appendix - A) to ensure accuracy and precision in data collection (Singh and Kathuria, 2016; Konuk, 2019; Hena *et al.*, 2021a; Hena *et al.*, 2021b; Hena *et al.*, 2022a; Hena *et al.*, 2022b; Hena *et al.*, 2023).

2.3 Recruitment of participants / consumers:

The non-probability purposive sampling method was adopted for recruitment of the participants / consumers because researchers were targeting a specific group of participants / consumers as they are the major consumers of branded bread (Singh and Kathuria, 2016; Hena *et al.*, 2021a; Hena *et al.*, 2021b; Hena *et al.*, 2022a; Hena *et al.*, 2022b; Hena *et al.*, 2023). The present study was comprised of 500 participants / consumers across four universities of Hisar, Haryana. A total number of participants from Haryana Agricultural University, Guru Jambheshwar University of Science and Technology, Lala Lajpat Rai University of Veterinary and Animal Sciences and Om Sterling Global University, Hisar, Haryana were 125, 125, 125 and 125 respectively. The participants / consumers comprised of 58.2% males and 41.8% females with the ages ranging from 18 to 65 years. The participants / consumers comprised of 51.8% single and 48.2% married, in which 57.2% were unemployed and 42.8% were employed. The educational level of the participants / consumers ranged from senior secondary school to doctoral degree. The annual family income of the participants / consumers ranged from US$ 950 to US$ 37500. The sample size of 500 participants / consumers taken in the present study was more than the estimated sample size of 385 as well as higher than 400 as recommended for a population over 0.25 million with a confidence level of 95% and 5% margin of error (The Research Advisor, 2006; Singh and Kathuria, 2016; Hena *et al.*, 2021a; Hena *et al.*, 2021b; Hena *et al.*, 2023). Total 37 participants / consumers were eliminated because they did not respond / provide in-complete information. The final sample size was 463 which resulted in a response rate of 92.60%.

2.4 Data collection:

The data were collected from teaching and non-teaching staff and students across four universities i.e. Haryana Agricultural University, Guru Jambheshwar University of Science and Technology, Lala Lajpat Rai University Veterinary and Animal Sciences and Om Sterling Global University in Hisar, Haryana. Structured and pre-tested questionnaires were distributed to 500 participants ⁄ consumers in four universities. The researcher's distributed the questionnaire to the participants ⁄ consumers and briefs them about the purpose and objectives of the study. The influence of aforementioned determinants on purchase intention and consumption of branded bread were determined on five point likert scale (Strongly disagree = 1, disagree = 2, don not know = 3, agree = 4, strongly agree = 5). The participants were asked to choose one from 1 to 5 for each question (Singh and Kathuria, 2016; Hena *et al.*, 2021a; Hena *et al.*, 2021b; Hena *et al.*, 2022a; Hena *et al.*, 2022b; Hena *et al.*, 2023).

2.5 Data analysis:

The statistical software SPSS version 24 was used to determine mean, standard deviation, skewness, and kurtosis. Further, SPSS was employed to determine Cronbach's alpha to assess internal consistency and reliability of questionnaire. The AMOS software version 23 was used to perform confirmatory factor analysis (CFA) and structural equation modeling (SEM). The CFA was carried out to estimate factor loading, composite reliability, average variance extracted, and model fit indices. The composite reliability of the constructs / determinants of the questionnaire was determine to examine the reliability of measurement model (Singh and Kathuria, 2016; Hena *et al.*, 2021a; Hena *et al.*, 2021b; Hena *et al.*, 2022a; Hena *et al.*, 2022b; Hena *et al.*, 2023). The factor loading, average variance extracted and correlations were determined to assess the convergent and discriminant validity of measurement model (Contini *et al.*, 2018; Hena *et al.*, 2021a; Hena *et al.*, 2021b; Hena *et al.*, 2022a; Hena *et al.*, 2022b; Hena *et al.*, 2023). The statistical indices such as comparative fit index (CFI), Tucker–Lewis index (TLI), goodness of fit index (GFI), root mean square error of approximation (RMSEA) and standardized root mean-square residual (SRMR) and χ^2/df (Chi square/ degree of freedom) were determined to assess the fit of the measurement and structural models. Standardized estimate / path co-efficient (ß), t-value and p-value were determines to test the proposed hypotheses (Rezai *et al.*, 2014; Singh and Kathuria, 2016; Konuk, 2018; Hena *et al.*, 2021a; Hena *et al.*, 2021b; Hena *et al.*, 2022a; Hena *et al.*, 2022b; Hena *et al.*, 2023).

III. RESULTS

3.1 Descriptive statistics:

The mean participant score of the items revealed that the "easy to prepare" within convenience orientation, "long working hours" within time scarcity, "limited knowledge about cooking" within cooking skills, "good flavor" within sensory appeal, "contains natural ingredients" within nutritional quality, "contains no hormones" within safety consciousness, "low sugar content" within health consciousness, "not expensive" within perceived price, "ingredients printed on packet" within product information, "natural ingredients for processing of food" within processing technology and "good quality and appearance of packaging" within packaging quality were the most important factors in relation to purchase intention and consumption of branded bread (Table 1).

TABLE 1
FACTOR LOADING, CRONBACH'S ALPHA, COMPOSITE RELIABILITY AND AVERAGE VARIANCE EXTRACTED OF THE DETERMINANTS INFLUENCING CONSUMER PURCHASE INTENTION AND CONSUMPTION OF BRANDED BREAD

Construct	Item	Mean score	Factor loading	p – value	Cronbach's alpha	Composite reliability	Average variance extracted
Convenience orientation (CNV)	• CON 1	4.71	0.787	***	**0.868**	**0.855**	**0.665**
	• CON 2	3.71	0.829	***			
	• CON 3	4.34	0.775	***			
	• CON 4	4.19	0.796	***			
	• CON 5	4.6	0.887	***			
Time scarcity (TS)	• TS 1	4.41	0.851	***	**0.874**	**0.842**	**0.611**
	• TS 2	4.33	0.752	***			
	• TS 3	4.26	0.718	***			
	• TS 4	3.9	0.875	***			
	• TS 5	3.72	0.712	***			
Cooking Skill (CKS)	• CKS 1	3.89	0.726	***	**0.863**	**0.83**	**0.627**
	• CKS 2	3.51	0.791	***			
	• CKS 3	3.41	0.813	***			
	• CKS 4	3.25	0.835	***			
Sensory appeal (SEN)	• SEN 1	4.39	0.785	***	**0.835**	**0.901**	**0.648**
	• SEN 2	4.59	0.813	***			
	• SEN 3	4.66	0.789	***			
	• SEN 4	4.45	0.772	***			
	• SEN 5	4.69	0.863	***			
Nutritional quality (QUL)	• QUL 1	3.88	0.804	***	**0.779**	**0.808**	**0.695**
	• QUL 2	3.61	0.814	***			
	• QUL 3	3.41	0.875	***			
	• QUL 4	3.11	0.856	***			
	• QUL 5	4.54	0.816	***			
	• QUL 6	4.16	0.837	***			
Safety consciousness (SFTY)	• SFTY 1	4.62	0.714	***	**0.885**	**0.916**	**0.687**
	• SFTY 2	3.13	0.795	***			
	• SFTY 3	4.44	0.888	***			
	• SFTY 4	4.62	0.863	***			
	• SFTY 5	4.07	0.874	***			
Health consciousness (HLT)	• HLT 1	3.81	0.843	***	**0.879**	**0.904**	**0.654**
	• HLT 2	4.33	0.764	***			
	• HLT 3	4.43	0.816	***			
	• HLT 4	4.48	0.761	***			
	• HLT 5	4.27	0.855	***			
Perceived price (PRC)	• PRC 1	4.62	0.865	***	**0.865**	**0.896**	**0.685**
	• PRC 2	3.54	0.799	***			
	• PRC 3	3.1	0.819	***			
	• PRC 4	4.22	0.824	***			

Product information (PIF)	• PIF 1	4.62	0.876	***	**0.895**	**0.913**	**0.68**
	• PIF 2	4.51	0.783	***			
	• PIF 3	3.75	0.805	***			
	• PIF 4	4.34	0.839	***			
	• PIF 5	3.76	0.818	***			
Processing technology (PCT)	• PCT 1	4.2	0.868	***	**0.898**	**0.919**	**0.694**
	• PCT 2	3.67	0.821	***			
	• PCT 3	4.08	0.833	***			
	• PCT 4	4.46	0.829	***			
	• PCT 5	4.37	0.816	***			
Packaging quality (PKG)	• PKG 1	4.62	0.777	***	**0.896**	**0.914**	**0.683**
	• PKG 2	4.33	0.788	***			
	• PKG 3	3.87	0.865	***			
	• PKG 4	4.25	0.834	***			
	• PKG 5	3.93	0.864	***			
Purchase Intention (PI)	• PI 1	3.17	0.773	***	**0.922**	**0.941**	**0.699**
	• PI 2	4.06	0.863	***			
	• PI 3	4.71	0.842	***			
	• PI 4	4.46	0.821	***			
	• PI 5	4.67	0.819	***			
	• PI 6	4.09	0.847	***			
	• PI 7	3.97	0.883	***			
Consumption (CON)	• CON 1	4.65	0.848	***	**0.926**	**0.948**	**0.725**
	• CON 2	4.45	0.829	***			
	• CON 3	3.87	0.879	***			
	• CON 4	3.41	0.825	***			
	• CON 5	4.26	0.856	***			
	• CON 6	4.09	0.876	***			
	• CON 7	4.05	0.849	***			

Measurement model fit indices: Comparative fit index (CFI) = 0.928; Tucker-Lewis index (TLI) = 0.923; Goodness of fit index (GFI) =0.919; Root mean square error of approximation (RMSEA) = 0.077; Standardized mean square residual (SRMR) =0.050, Significant at $p \leq 0.01$; Skewness = -0.962 to 0.607 Kurtosis = -0.763 to 1.996

The skewness for different items of convenience orientation, time scarcity, cooking skills, sensory appeal, nutritional quality, safety consciousness, health consciousness, perceived price, product information, processing technology, packaging quality, purchase intention and consumption of branded bread ranged from -0.962 to 0.607, which falls within threshold value of -1 to 1. The kurtosis for different items of convenience orientation, time scarcity, cooking skills, sensory appeal, nutritional quality, safety consciousness, health consciousness, perceived price, product information, processing technology, packaging quality, purchase intention and consumption constructs ranged from -0.763 to 1.996, which falls within threshold value of -2 to 2 (Table 1). The results revealed that the participant score / data for different items of convenience orientation, time scarcity, cooking skills, sensory appeal, nutritional quality, safety consciousness, health consciousness, perceived price, product information, processing technology, packaging quality, purchase intention and consumption constructs were normally distributed (Muthen and Kaplan, 1985; Rezai *et al.*, 2014; Hena *et al.*, 2021a; Hena *et al.*, 2021b; Hena *et al.*, 2022a; Hena *et al.*, 2022b; Hena *et al.*, 2023).

3.2 Measurement model:

The factor loading for different items of convenience orientation, time scarcity, cooking skills, sensory appeal, nutritional quality, safety consciousness, health consciousness, perceived price, product information, processing technology, packaging quality, purchase intention and consumption of branded bread were significant ($p \leq 0.01$). The factor loading for different items of the convenience orientation, time scarcity, cooking skills, sensory appeal, nutritional quality, safety consciousness, health consciousness, perceived price, product information, processing technology, packaging quality, purchase intention and consumption ranged from 0.718 to 0.888. The factor loading for all items of the constructs exceeded the threshold value of 0.70, therefore, all the items of the constructs / determinants were included for the interpretation of the factors influencing consumer purchase intention and consumption of branded bread (Hair *et al.*, 2006; Hena *et al.*, 2021a; Hena *et al.*, 2021b; Hena *et al.*, 2022a; Hena *et al.*, 2022b; Hena *et al.*, 2023). The Cronbach's alpha of the determinants, i.e. convenience orientation, time scarcity, cooking skills, sensory appeal, nutritional quality, safety consciousness, health consciousness, perceived price, product information, processing technology and packaging quality influencing consumer purchase intention and consumption of branded bread ranged from 0.779 to 0.926, which exceeded the threshold value of 0.70 (Table 1). The composite reliability of convenience orientation, time scarcity, cooking skills, sensory appeal, nutritional quality, safety consciousness, health consciousness, perceived price, product information, processing technology, packaging quality, purchase intention and consumption of branded bread ranged from 0.808 to 0.948, which exceeded the threshold value of 0.70 (Table 1). The Cronbach alpha and composite reliability demonstrate good internal consistency and reliability of the questionnaire to assess the role of convenience orientation, time scarcity, cooking skills, sensory appeal, nutritional quality, safety consciousness, health consciousness, perceived price, product information, processing technology and packaging quality on consumer's purchase intention and consumption of branded bread (Hair *et al.*, 2006; Konuk, 2019; Hena *et al.*, 2021a; Hena *et al.*, 2021b; Hena *et al.*, 2022a; Hena *et al.*, 2022b; Hena *et al.*, 2023).

Average Variance Extracted (AVE) for the determinants i.e. convenience orientation, time scarcity, cooking skills, sensory appeal, nutritional quality, safety consciousness, health consciousness, perceived price, product information, processing technology and packaging quality influencing consumer purchase intention and consumption of branded bread ranged from 0.611 to 0.725, which exceeded the threshold value of 0.50. The factor loading and average variance extracted values confirmed convergent validity of the measurement model (Hair *et al.*, 2006; Konuk, 2019; Hena *et al.*, 2021a; Hena *et al.*, 2021b; Hena *et al.*, 2022a; Hena *et al.*, 2022b; Hena *et al.*, 2023). The CFI was 0.928 (≥ 0.90), TLI was 0.923(≥ 0.90), GFI was 0.919 (≥ 0.90), RMSEA was 0.077 (≤ 0.080) and SRMR was 0.050 (≤ 0.080) which were within the recommended threshold values (Table 1). The CFI, TLI, GFI, RMSEA and SRMR values demonstrate the good fit of the measurement model (Singh and Kathuria, 2016; Soon, 2018; Hena *et al.*, 2021a; Hena *et al.*, 2021b; Hena *et al.*, 2022a; Hena *et al.*, 2022b; Hena *et al.*, 2023). The square root of average variance extracted (diagonal values) were higher than the correlation estimates amongst constructs (Table. 2), which confirmed the discriminant validity of measurement model (Fornell and Larcker, 1981; Singh and Kathuria, 2016; Konuk, 2019; Hena *et al.*, 2021a; Hena *et al.*, 2021b; Hena *et al.*, 2022a; Hena *et al.*, 2022b; Hena *et al.*, 2023).

TABLE 2
DISCRIMINANT VALIDITY OF THE MEASUREMENT MODEL

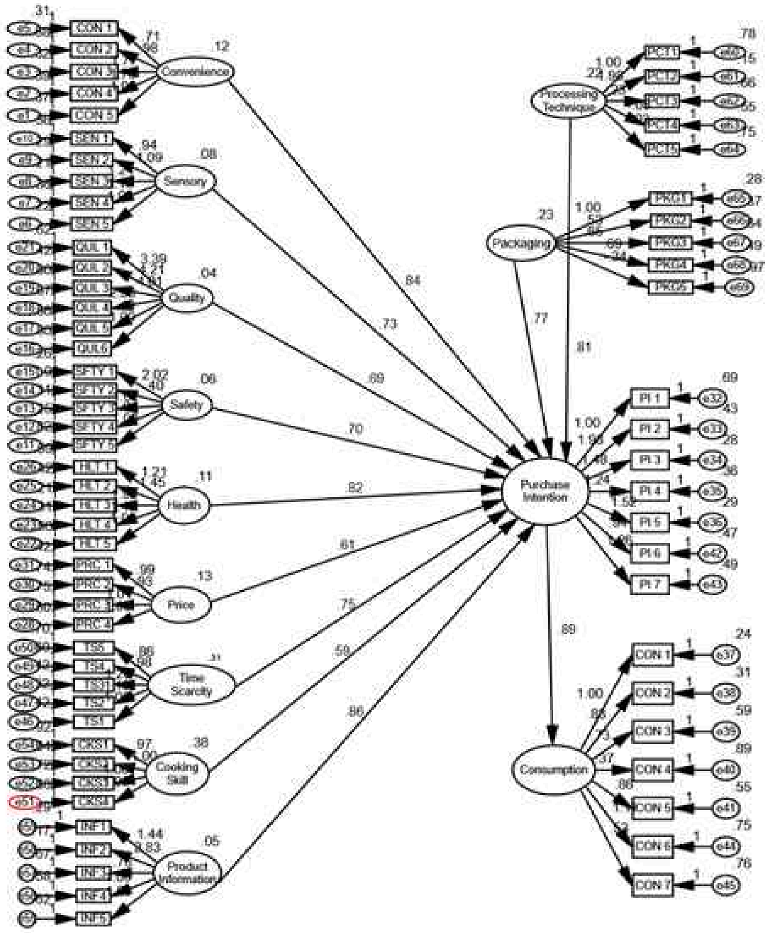
	CNV	TS	CKS	SEN	QUL	SFTY	HLT	PRC	PIF	PCT	PKG	PI	CON
CNV	.813												
TS	.782	.822											
CKS	.744	.695	.801										
SEN	.660	.677	.726	.852									
QUL	.788	.730	.566	.578	.838								
SFTY	.543	.609	.540	.688	.587	.720							
HLT	.685	.742	.404	.589	.602	.624	.798						
PRC	.536	.567	.714	.778	.487	.450	.647	.808					
PIF	.722	.708	.738	.797	.538	.676	.723	.721	.798				
PCT	.585	.461	.662	.516	.542	.415	.706	.626	.599	.871			
PKG	.512	.498	.653	.769	.599	.611	.713	.780	.498	.533	.781		
PI	.615	.578	.781	.684	.697	.429	.685	.699	.626	.705	.775	.809	
CON	.638	.773	.763	.648	.815	.584	.691	.769	.751	.760	.698	.770	.921

3.3 Structural model:

The structural equation modeling (SEM) approach was adopted to examine the association between convenience orientation, time scarcity, cooking skills, sensory appeal, nutritional quality, safety consciousness, health consciousness, perceived price, product information, processing technology and packaging quality with consumer purchase intention and consumption of branded bread. The CFI was 0.934 (≥ 0.90), TLI was 0.938 (≥ 0.90), GFI was 0.966 (≥ 0.90), RMSEA was 0.071(≤ 0.80), SRMR was 0.072(≤ 0.80) and χ^2/df was 3.9(≤5.0), which were within the acceptable range (Fig. 2). The CFI, TLI, GFI, RMSEA, SRMR and χ^2/df values demonstrate a good fit of the structural model (Hu and Bentler, 1999; Rezai *et al.*, 2014;

Singh and Kathuria, 2016; Contini *et al.*, 2018; Hena *et al.*, 2021a; Hena *et al.*, 2021b; Hena *et al.*, 2022a; Hena *et al.*, 2022b; Hena *et al.*, 2023).

The results of the structural model presented in Figure 2 and Table 3, demonstrate the magnitude of association for convenience orientation, time scarcity, cooking skills, sensory appeal, nutritional quality, safety consciousness, health consciousness, perceived price, product information, processing technology and packaging quality with consumer's purchase intention and consumption of branded bread. Hypothesis 1 (H1) which proposed positive relationship between convenience orientation and purchase intention of branded bread was supported because standardized estimate (ß) of path of structural model was significant (ß = 0.84, t-value = 22.452, $p \leq 0.01$). Hypothesis 2 (H2) which proposed positive relationship between time scarcity and purchase intention of branded bread was supported because standardized estimate (ß) of path of structural model was significant (ß = 0.75, t-value =19.526, $p \leq 0.01$). Hypothesis 3 (H3) which proposed positive relationship between lack of cooking skills and purchase intention of branded bread was supported because standardized estimate (ß) of path of structural model was significant (ß = 0.59, t-value =26.408, $p \leq 0.01$). Hypothesis 4 (H4), which proposed positive relationship between sensory appeal and purchase intention of branded bread was supported because standardized estimate (ß) of path of structural model was significant (ß = 0.73, t-value = 33.587, $p \leq 0.01$). Hypothesis 5 (H5) which proposed positive relationship between nutritional quality and purchase intention of branded bread was supported because standardized estimate (ß) of path of structural model was significant (ß = 0.69, t-value = 27.654, $p \leq 0.01$). Hypothesis 6 (H6) which proposed positive relationship between safety consciousness and purchase intention of branded bread was supported because standardized estimate (ß) of path of structural model was significant (ß = 0.70, t-value = 11.325, $p \leq 0.01$). Hypothesis 7 (H7) which proposed positive relationship between health consciousness and purchase intention of branded bread was supported because standardized estimate (ß) of path of structural model was significant (ß = 0.82, t-value = 23.687, $p \leq 0.05$).



Structural model fit indexes: CFI: 0.934; TLI: 0.938; GFI: 0.966; RMSEA: 0.071; SRMR: 0.072; χ^2/df = 3.9.

FIGURE 2: Structural equation modelling to assess the role of convenience orientation, time scarcity, cooking skills, sensory appeal, nutritional quality, safety consciousness, health consciousness, perceived price, product information, processing technology and packaging quality on purchase intention and consumption of branded bread.

TABLE 3
STRUCTURAL MODEL RESULTS TO EXAMINE THE ASSOCIATION BETWEEN CONVENIENCE ORIENTATION, TIME SCARCITY, COOKING SKILLS, SENSORY APPEAL, NUTRITIONAL QUALITY, SAFETY CONSCIOUSNESS, HEALTH CONSCIOUSNESS, PERCEIVED PRICE, PRODUCT INFORMATION, PROCESSING TECHNOLOGY AND PACKAGING QUALITY WITH PURCHASE INTENTION, CONSUMPTION OF BRANDED BREAD.

Hypothesis	Structural Path	Standardized estimate (ß)	Standard error (SE)	t-value	p - value	Results
H1	Convenience orientation → Purchase intention	0.84	0.024	22.452	***	Accepted
H2	Time scarcity → Purchase intention	0.75	0.043	19.526	***	Accepted
H3	Lack of cooking skill → Purchase intention	0.59	0.040	26.408	***	Accepted
H4	Sensory appeal → Purchase intention	0.73	0.016	33.587	***	Accepted
H5	Nutritional quality→ Purchase intention	0.69	0.018	27.654	***	Accepted
H6	Safety consciousness → Purchase intention	0.70	0.021	11.325	***	Accepted
H7	Healthiness consciousness → Purchase intention	0.82	0.025	23.687.	***	Accepted
H8	Perceived price → Purchase intention	0.61	0.034	16.874	***	Accepted
H9	Product information→ Purchase intention	0.86	0.014	26.571	***	Accepted
H10	Novel processing Technology → Purchase intention	0.81	0.110	29.634	***	Accepted
H11	Packaging quality → Purchase intention	0.77	0.45	15.392	***	Accepted
H12	Purchase intention → Consumption	0.84	0.043	66.811	***	Accepted

****** Significant at $p \leq 0.01$***

Hypothesis 8 (H8) which proposed positive relationship between perceived price and purchase intention of branded bread was supported because standardized estimate (ß) of path of structural model was significant (ß = 0.61, t-value = 16.874, $p \leq 0.01$). Hypothesis 9 (H9) which proposed positive relationship between product information and purchase intention of branded bread was supported because standardized estimate (ß) of path of structural model was significant (ß = 0.86, t-value = 26.571, $p \leq 0.01$). Hypothesis 10 (H10) which proposed positive relationship between novel processing technology and purchase intention of branded bread was supported because standardized estimate (ß) of path of structural model was significant (ß = 0.81, t-value = 29.634, $p \leq 0.01$). Hypothesis 11 (H11) that proposed positive relationship between packaging quality and purchase intention of branded bread was supported because standardized estimate (ß) of path of structural model was significant (ß = 0.77, t-value = 15.392, $p \leq 0.01$). Hypothesis 12 (H12), that proposed positive relationship between purchase intention and consumption of branded bread was also supported because standardized estimate (ß) of the path of structural model was statistically significant (ß = 0.84, t-value = 66.811, $p \leq 0.01$).

IV. DISCUSSION

Consumer's worldwide seek convenience in meal solution due to significant increase in nuclear and dual working families, long and irregular working hours, competitive and busy lifestyle, lack of cooking skills and motivation, changing food related lifestyle and multiple responsibilities. Convenience orientation is one of the most important factor influencing consumer's food choice. The mean participant's / consumer's score and results of the structural model indicate that convenience orientation had positive and significant role in influencing consumer's purchase intention and consumption of branded bread. The path analyses of the structural model reveal that convenience orientation was positively associated with purchase intention and consumption of branded bread. Further, the mean participant's / consumer's score of items demonstrate that easy to prepare, minimum physical effort to clean up and makes life easier were the key factors within convenience orientation construct that positively influenced consumer's purchase intention and consumption of branded bread. The results of the previous studies revealed that convenience orientation was the important determinant in influencing consumer's purchase decision and consumption of convenience food (Hena *et al.*, 2021b).

Time scarcity induced by multiple factors, results in modification of food consumption behaviour of consumer. Long working hours, busy lifestyle, hectic work schedule, desire to maximize leisure time and competitive environment are the key factors within the time scarcity construct which play significant and positive role in influencing and motivating consumer's for convenience food choice such as branded bread. The mean participant's / consumer's score for items of time scarcity determinant and analysis of structural model indicate that time scarcity had positive and significant effect on consumer's purchase intention and consumption of branded bread. The results of path analysis of structural model demonstrate positive relationship between time scarcity and purchase intention and consumption of branded bread. Further, mean participant's/ consumer's score of items indicate that long working hours, hectic work schedule and busy lifestyle were the most important factors within time scarcity construct, which positively influenced consumer's purchase intention and consumption of branded bread. The findings of the previous studies support the results of the present study (Jabs and Devine, 2006; Beshara *et al.*, 2010; Cecilia *et al.*, 2016; Djupegot *et al.*, 2017; Contini *et al.*, 2018; Leenders *et al.*, 2019; Hena *et al.*, 2023).

Cooking food from scratch required significant amount of time and physical and mental effort as well as cooking knowledge and experience. Lack of cooking skills and motivation and changing food related lifestyles significantly rise the demand and consumption of convenience food products like brand bread as it saves time, energy and physical effort. The mean participant's / consumer's score and results of structural model analysis indicate that lack of cooking skills and motivation had significant and positive effect on consumer's purchase intention and consumption of branded bread. The path analysis of the structural model demonstrates positive association between lack of cooking skills and purchase intention and consumption of branded bread. Furthers, limited cooking knowledge within cooking skills constructs was the key factor influencing purchase intention influencing purchase intention and consumption of branded bread. The results obtained in the present study are in agreement with the findings of the previous studies (Brunner *et al.*, 2010; Hartmann *et al.*, 2013; Namin *et al.*, 2020; Hena *et al.*, 2023).

Sensory attributes such as taste, colour, appearance, texture and smell are important factors influencing consumer's purchase decision and consumption of food products. Sensory appeal play significant role in motivating and deriving consumers towards purchase and consumption of convenience food products like branded bread. The participant's /consumer's score for sensory appeal and outcomes of the structural model indicate that sensory appeal had significant effect on consumer's purchase intention and consumption of branded bread. The standardized estimate / path coefficient (ß) of the structural model demonstrate the positive relationship between sensory appeal and purchase intention and consumption of branded bread. The results further indicate that pleasant appearance, appealing texture, good taste, nice smell and good flavour within sensory appeal were the key factors, which motivate and drive consumers towards purchase and consumption of branded bread. Previous studies carried out elsewhere indicate that sensory appeal (taste, appearance, freshness, flavour) was important determinant which positively influenced consumer's purchase decision and consumption of branded bread / bakery products, support the results of the present study (Dewettinck *et al.*, 2008; Heenan *et al.*, 2009; Tikkanen and Vääriskoski, 2010; Skorepa and Picha, 2016; Lakshmi, 2016; Jadhav and Chavan, 2019; Sajdakowska *et al.*, 2019; Khannal, 2020). Hena *et al.* (2021a) indicate that consumers in India give more attention on sensory appeal during purchase and consumption of Convenience food.

Nutritional quality generally includes nutritive value, mineral content, protein content, vitamin content, fiber content and natural ingredients of food products. Quality conscious consumers are willing to pay premium price for high quality food products. Consumers generally perceived that advanced and novel food processing technologies improves quality of processed food products (Ohja *et al.*, 2015; Misra *et al.*, 2017; Hena *et al.*, 2022a,). In past two decades consumer's focuses more on nutritional quality of bakery products (Tikkanen and Vääriskoski, 2010; Lakshmi, 2016; Lădaru *et al.*, 2021). The participant's / consumer's score of nutritional quality and results of the structural model indicate that nutritional quality had significant and positive influence on purchase intention and consumption of branded bread. The standardized estimate / path coefficient (ß) of structural model indicate positive relationship / association between nutritional quality and purchase intention and consumption of branded bread. Furthermore, natural ingredients and food quality certification within the nutritional quality were the most important factors positively influencing consumer's purchase intention and consumption of branded bread. The previous studies carried out elsewhere support the results of the present study (Dewettinck *et al.*, 2008; Tikkanen and Vääriskoski, 2010; Moslehpour *et al.*, 2015; Lakshmi, 2016; Khanal, 2020; Lădaru *et al.*, 2021). Hena *et al.* (2021a) demonstrate that food quality certification from regulatory agency was the most important factor in influencing consumer's purchase intention and consumption of convenience food.

Food safety is another crucial determinant influencing consumer's food choice. In recent years, consumers are more concerned about food safety issues because it is directly linked with public health (Omari and Frempong, 2015; Hena *et al.*, 2021a). The mean participant's / consumer's score of food safety construct and analysis of structural model indicate that food safety consciousness had positive and significant influence on consumer's purchase intention and consumption of branded bread. The standardized estimate / path coefficient (ß) of structural model demonstrate positive relationship between food safety consciousness and purchase intention and consumption of branded bread. Further, consumer's belief that it does not contained harmones, artificial ingredients, insecticides and pesticides, which in-turn drive consumers towards purchase and consumption of branded bread. Previous studies carried out elsewhere also revealed that food safely is an important determinant influencing consumer's purchase decision and consumption of convenience food like branded bread (Emeje *et al.*, 2010; Olusegun *et al.*, 2015; Omari and Frempong, 2015; Moreb *et al.*, 2017; Hena *et al.*, 2021a). Misra *et al.* (2017) reported that novel food processing technology reduced processing time and energy consumption as well as significantly improved the quality and safety standards of convenience food.

Health is a prime concerns of consumer's while purchasing and consuming processed food products. Health benefits have become most critical determinant that motivate and drive consumer's to choose specific food product / brand. Health conscious consumer's prefers safe and healthy food products. The mean participant's / consumer's score of health construct and results of structural model demonstrate that health consciousness had positive and significant influence on purchase intention and consumption of branded bread. Standardized estimate / path coefficient (ß) of structural model demonstrate positive association between health consciousness and purchase intention and consumption of branded bread. Further, the mean score of the different items of health construct indicate that consumer's satisfied with the health benefits of branded bread because it is low in fat, salt and sugar contents as well as provide balanced diet. The findings of the previous studies carried out elsewhere for bread, support the results of the present study (Dewettinck *et al.*, 2008; Sajdakowska *et al.*, 2019; Engindeniz and Bolatova, 2021; Hena *et al.*, 2021a; Wambugu and Musyoka, 2022).

Family income, disposable income and food price are important economic drivers influencing consumer's food choice. The food price is one of the most important determinant, which influence consumer's purchase decision and consumption of branded bread. In current scenario, competitive price and promotional offer are main strategy of food industry / marketing agencies to attract consumers for purchasing their food products (Deliens *et al.*, 2016; Hena *et al.*, 2022b). The mean participant's / consumer's score of price construct and outcome of the structural model demonstrate that perceived price had significant and positive influence on purchase intention and consumption of branded bread. Standardized estimate / path coefficient (ß) of structural model indicate positive relationship between perceived price and purchase intention and consumption of branded bread. Further, competitive price, promotional offer and good value for money were the most important factors, which motivate and drive consumer's for purchase and consumption of branded bread. Previous studies carried out elsewhere indicated that food price was the important determinant associated with purchase intention and consumption of branded bread / bakery products, which supports the results of the current study (Tikkanen and Vääriskoski, 2010; Moslehpour *et al.*, 2015; Skorepa and Picha, 2016; Khanal, 2020; Engindeniz and Bolatova, 2021; Al Togar and Al Hakim, 2022).

Informations regarding sensory attributes, nutritional quality, safety measure, healthiness, ingredients, cooking instruction, shelf life, country / place of origin, price and certification are the key attributes of food labelling / product information, which generally assess by consumers before purchasing food products. Therefore, it is important to provide true and authentic information to the consumer's regarding the food products through labelling /product information inorder to attract, motivate and satisfy the consumer's. The mean participant's / consumer's score of product information / labelling construct and results of the structural model analysis demonstrate that product information / labelling had significant and positive effect on consumer's purchase intention and consumption of branded bread. Standardized estimate / path coefficient (ß) of structural model exhibit positive association between product information / labelling and purchase intention and consumption of branded bread. Further, information regarding ingredients, nutritional facts and quality and safety certification were the key factors that positively influenced consumer's purchase intention and consumption of branded bread. The findings of the previous research carried out elsewhere supports the results of the present study (Dewettinck *et al.*, 2008; Hena *et al.*, 2022a).

Food processing and preservation technologies improve sensory appeal, nutritional quality, safety attributes and healthiness of processed food products. Consumer's generally perceive that novel food processing technologies such as high pressure processing (HPP), pulsed electric field (PEF) and cold plasma improves and maintain nutritive value, naturalness, freshness, taste, appearance, aroma, shelf life and healthiness of processed foods as well as minimize environmental damage. The mean participant's / consumer's score and analysis of the structural model demonstrate that novel food processing technology had significant and positive effect on consumer's purchase intention and consumption of branded bread. Standardized estimate /

path coefficient (ß) of structural model exhibit positive association between novel food processing technology and purchase intention of branded bread. Further, consumer's perceived that food processing technology follow international standard and improve sensory appeal, shelf life, nutritional quality and safety attributes as well as it is environmental friendly, which inturn drive consumer's towards purchase and consumption of branded bread. Previous studies carried out elsewhere reported the similar results for processed food products (Ojha *et al.*, 2015; Misra *et al.*, 2017; Hena *et al.*, 2022a).

Food packaging is one of the most important determinant, which influences consumer's perception, purchase decision and consumption of processed food products. The innovative food packaging technology enhance quality and safety of food products. The novel food packaging technologies such as active, intelligent and biodegradable packaging prolong shelf life, maintain quality and safety as well as protect and maintain appearance, taste, colour, aroma and freshness of food products. The visual packaging attributes such as information regarding ingredients, nutritive value, shelf life, price, place of origin, cooking instruction and quality and safety certification play significant role in influencing consumer's purchase decision and consumption of processed food products (Heide and Olsen, 2017; Licciardello, 2017; Majid *et al.*, 2018). The mean participant's / consumer’s score and results of structural model indicate that packaging quality had significant and positive effect on consumer's purchase intention and consumption of branded bread. Standardized estimate / path coefficient (ß) of structural model demonstrate positive relationship between packaging quality and purchase intention and consumption of branded bread. Further, appearance, quality, durability, convenience and environmental friendly attributes of packaging were the important factors that positively influenced consumer's purchase intention and consumption of branded bread. The findings of the previous studies carried out elsewhere supports the results of the present study (Tikkanen and Vääriskoski, 2010; Wyrwa and Barska, 2017; Majid *et al.*, 2018; Jadhav and Chavan, 2019; Hena *et al.*, 2022a).

V. CONCLUSION

The outcome of the present study highlight the role of convenience orientation, time scarcity, cooking skill, sensory appeal, nutritional quality, safety consciousness, health consciousness, perceived price, product information, processing technology and packaging quality on purchase intention and consumption of branded bread. In order to understand the extent of association between aforementioned determinants and purchase intention and consumption of branded bread, confirmatory factor analysis (CFA) and structural equation modelling (SEM) approach were adopted. The results obtained for Cronbach's alpha, factor loading, composite reliability, average variance extracted and correlations estimates demonstrate good internal consistency and reliability of the questionnaire as well as confirmed the convergent and discriminant validity of measurement model. Statistical indices indicate good and acceptable fit of measurement and structural models with data. Standardized estimate / path coefficient (ß) of the structural model demonstrate significant and positive relationship between convenience orientation, time scarcity, lack of cooking skill, sensory appeal, nutritional quality, safety consciousness, health consciousness, perceived price, product information, novel processing technology and packaging quality with consumer's purchase intention and consumption of branded bread. Convenience orientation, health consciousness, product information / labelling and processing technology were the key determinants influencing consumer's purchase intention and consumption of branded bread in an academic environment. The outcome of this comprehensive study indicate that bakery industry should focus more on health attributes, provide true and authentic product information and employ novel processing and packaging technology in order to enhance trust and loyalty amongst the consumer's. Further, government regulatory agencies should implement strict food laws and regulations for production process, quality control, labelling and marketing to provide safe and healthy branded bread to consumers.

ACKNOWLEDGEMENTS

The authors wish to acknowledge all the teaching and non-teaching staff and students across four universities i.e. Haryana Agricultural University, Guru Jambheshwar University of Science and Technology, Lala Lajpat Rai University Veterinary and Animal Sciences and Om Sterling Global University in Hisar, Haryana, India who consented to be part of the survey.

All the data presented in the manuscript were extracted from the thesis “Assessing the role of determinants on consumer’s purchase intention and consumption of processed branded bread in an Academic Environment” conducted at the Department of Processing and Food Engineering, Sam Higginbottom University of Agricultural, Technology and Sciences, Prayagraj – 211007 Uttar Pradesh, India.

REFERENCES

[1] Al Togar, M. H. and Al Hakim, Y. R. (2022). The Effect of Price Perception, Product Diversity, Service Quality and Store Image on Purchase Intention in Bread Products. *Journal of Marketing and Business Research (MARK)*, 2(1): 35-46. DOI: https://doi.org /10.56348/mark.v2i1.42

[2] Bandara, B. E. S., De Silva, D.A. M., Maduwanthi, B. C. H. and Warunasinghe, W.A. A.I. (20016). Impact of food labeling information on consumer purchasing decision: with special reference to faculty of Agricultural Sciences. *Procedia Food Science*, 6: 309-313. DOI: https://doi.org/10.1016/j.profoo.2016.02.061

[3] Beshara, M., Hutchinson, A. and Wilson, C. (2010). Preparing meals under time stress. The experience of working mothers. *Appetite*, 55(3): 695-700. DOI: 10.1016/j.appet.20 10.10.003

[4] Braghieri, A., Piazzolla, N., Carlucci, A., Bragaglio, A. and Napolitano, F. (2016). Sensory properties, consumer liking and choice determinants of Lucanian dry cured sausages. *Meat Science*, 111: 122-129. DOI: https://doi.org /10.1016/j.meatsci.2015.09. 003

[5] Brunner, T. A., Horst, K. V. D. and Siegrist, M. (2010). Convenience food products: Drivers for consumption. *Appetite*, 55(3): 498-506. DOI: https://doi.org/10.1016/j.appe t.2010.08.017

[6] Cecilia, G., Adriana, B., Monica, M., Mihaela, T., Mark, S., Mironescu, I. D. and Tita, O. (2016). Consumer perceptions of nutrition and health claims from food labels in Romania. *Journal of Hygienic Engineering and Design*, 16: 13-18. URL: http:// www.jhed.mk/filemanager/JHED%20Vol.%2016/02.%20FQ&S/01.%20Full%20paper%20-% 20Cecilia%20Georgescu.pdf

[7] Compaore-Sereme, D., Hama-Ba, F., Tapsoba, F. W., Manner, H., Maina, N. H., Dicko, M. H. and Sawadogo-Lingani, H. (2023). Production and sensory evaluation of composite breads based on wheat and whole millet or sorghum in the presence of Weissella confusa A16 exopolysaccharides. *Heliyon*, 9(3): 13837. DOI: https:// doi.org/10. 1016/j.heliyon.2023.e13837

[8] Contini, C., Boncinelli, F., Gerini, F., Scozzafava, G. and Casini, L. (2018). Investigating the role of personal and context- related factors in convenience foods consumption. *Appetite*, 126: 26-35. DOI: 10.1016/j.appet.2018.02.031

[9] Deliens, T., Deforche, B., Annemans, L., De Bourdeaudhuij, I. and Clarys, P. (2016). Effectiveness of Pricing Strategies on French Fries and Fruit Purchases among University Students: Results from an On-Campus Restaurant Experiment. *PloS ONE*, 11(11): e0165298. DOI: https://doi.org/10.1371/journal.pone.0165298

[10] Dewettinck, K., Van Bockstaele, F., Kühne, B., Van de Walle, D., Courtens, T. M. and Gellynck, X. (2008). Nutritional value of bread: Influence of processing, food interaction and consumer perception. *Journal of Cereal Science*, 48(2): 243-257. DOI: https://doi.org/10.1016/j.jcs.2008.01.003

[11] Di Vita, G., Blanc, S., Brun, F., Bracco, S. and D'Amico, M. (2019). Quality attributes and harmful components of cured meats: Exploring the attitudes of Italian consumers towards healthier cooked ham. *Meat Science*, 155: 8-15. DOI: https://doi.org/ 10.1016/ j.meatsci.2019.04.013

[12] Djupegot, I. L., Nenseth, C. B., Bere, E., Bjørnarå, H. B. T., Helland, S. H., Øverby, N. C. and Stea, T. H. (2017). The association between time scarcity, sociodemographic correlates and consumption of ultra-processed foods among parents in Norway: a cross-sectional study. *BMC Public Health*, 17(1): 1-8. DOI: https://doi.org/10.1186/s12889-017-4408-3

[13] Emeje, M. O., Ofoefule, S. I., Nnaji, A. C., Ofoefule, A. U. and Brown, S. A. (2010). Assessment of bread safety in Nigeria: Quantitative determination of potassium bromate and lead. *African Journal of Food Science*, 4(6): 394-397. URL: https://academ icjournals.org/article/article1380726152_Emeje%20et%20al.pdf

[14] Engindeniz, S. and Bolatova, Z. (2021). A study on consumption of composite flour and bread in global perspective. *British Food Journal*, 123(5): 1962-1973. DOI: https:// doi.org/10.1108/BFJ-10-2018-0714

[15] Fornell, C. and Larcker, D. F. (1981). Evaluating structural equation models with unobservable variables and measurement error. *Journal of Marketing Research*, 18: 39-50. DOI: https://doi.org/10.2307/3151312

[16] Grujic, S., Grujic, R., Petrovic, D., and Gajic, J. (2013). Knowledge of food quality and additives and its impact on food preference. *Acta Scientiarum Polonorum, Technologia Alimentaria*, 12(2): 215-222. URL: https://www.food.acta pol.net/volume12/issue2/10_ 2_2013.pdf

[17] Hair, J., Black, W., Rabin, B., Anderson, R., and Tatham, R. (2006). Multivariate data analysis. *New Jersey: Pearson Education Inc., 2006*.

[18] Hartmann, C., Dohle, S. and Siegrist, M. (2013). Importance of cooking skills for balanced food choices. *Appetite*, 65: 125-131. DOI: https://doi.org/10.1016/j.appet.201 3.01.016

[19] Heenan, S. P., Hamid, N., Dufour, J. P., Harvey, W. and Delahunty, C. M. (2009). Consumer freshness perceptions of breads, biscuits and cakes. *Food Quality and Preference*, 20(5): 380-390. DOI: https://doi.org/10.1016/j.foodqual.20 09.02.008

[20] Heide, M. and Olsen, S. O. (2017). Influence of packaging attributes on consumer evaluation of fresh cod. *Food Quality and Preference*, 60: 9-18. DOI: https://doi.org/ 10.1016/j.foodqual.2017.02.015

[21] Hena, I., Soni, P. and Yukongdi, V. (2021a). Role of Sensory Appeal, Nutrition Quality, Safety and Health Determinants on Convenience Food Choice in an Academic Environment. *Foods*, 10: 345. DOI: https://doi.org/10.33 90/foods10020345

[22] Hena, I., Soni, P. and Yukongdi, V. (2021b). Investigating the Role of Psychological, Social, Religious and Ethical Determinants on Consumers' Purchase Intention and Consumption of Convenience Food. *Foods*, 10(2): 237. DOI: https://doi.org /10.3390/ foods10020237

[23] Hena, I., Soni, P. and Yukongdi, V. (2022a). Understanding Consumer's Purchase Intention and Consumption of Convenience Food in an Emerging Economy: Role of Marketing and Commercial Determinants. *Journal of Agriculture and Food*, 10: 100399. DOI: https://doi.org/10.1016/j.jafr.2022.100399

[24] Hena, I., Soni, P. and Yukongdi, V. (2022b). Consumer's Purchase Intention and Consumption of Convenience Food: The Role of Socio-demographic and Economic Determinants. *Food Research*, 6 (4): 68-82. DOI: https://doi.org/10.26 656/fr.2017.6(4). 391

[25] Hena, I., Soni, P. and Yukongdi, V. (2023). Assessing the Consumers' Purchase Intention and Consumption of Convenience Food in Emerging Economy: The Role of Physical Determinants. *SAGE Open*, 13(1). DOI: https://doi. org/10.1177/21582440 221148434

[26] Hoek, A. C., Pearson, D., James, S. W., Lawrence, M. A. and Friel, S. (2017). Shrinking the food-print: A qualitative study into consumer perceptions, experiences and attitudes towards healthy and environmentally friendly food behaviours. *Appetite*, 108: 117-131. DOI: https://doi.org/10.1016/j.appet.2016.09.030

[27] Hu, L.T. and Bentler, P.M. (1999). Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. *Structural Equation Modeling*, 6: 1-55. DOI: https://doi.org/10.1080/10705519909540118

[28] Jabs, J. and Devine, C. M. (2006). Time scarcity and food choices: An overview. *Appetite*, 47(2):196-204. DOI: https:/ /doi.org/10.1016/j.appet.2006.02.014

[29] Jadhav, H. and Chavan, P. (2019). An analytical study on consumer buying behaviour for bakery products. Special Issue, Fostering Innovation, Integration and Inclusion Through Interdisciplinary Practices in Management, *International Journal of Trend in Scientific Research and Development (IJTSRD)*, Conference Issue – FIIITIPM 2019, 129-133. URL: https://www.ijtsrd .com/papers/ijtsrd 23083.pdf.

[30] Khanal, K. (2020). Dimensions of Nepalese bakery products and its impact on customers' satisfaction. *Management Dynamics*, 23(2): 1-12. DOI: https://doi.org/ 10.3126/md.v23i2.35800

[31] Konuk, F. A. (2019). The impact of retailer innovativeness and food healthiness on store prestige, store trust and store loyalty. *Food Research International*, 116: 724-730. DOI: https://doi.org/10.1016/j.foodres.2018.09.003

[32] Lădaru, G. R., Siminică, M., Diaconeasa, M. C., Ilie, D. M., Dobrotă, C. E., and Motofeanu, M. (2021). Influencing factors and social media reflections of bakery products consumption in Romania. *Sustainability*, 13(6): 3411. DOI: https://doi.org/10. 3390/su13063411

[33] Lakshmi, E. (2017). Consumer preference and quality of bakery product – Bread. *International Journal of Food, Nutrition and Dietetics*, 5(3): 41-44.DOI: http://dx. doi.org/10.21088/ijfnd.2322.0775.5317.1

[34] Leenders, M. A. A. M., Smidts, A. and Hajim, E. I. A. (2019). Ambient scent as a mood inducer in supermarkets: The role of scent intensity and time-pressure of shoppers. *Journal of Retailing Consumer Service*, 48: 270-280. DOI: https: //doi.org/10.1016/j.jret conser.2016.05.007

[35] Licciardello, F. (2017). Packaging, blessing in disguise. Review on its diverse contribution to food sustainability. *Trends in Food Science and Technology*, 65: 32-39. DOI: https://doi.org/10.1016/j.tifs.2017.05.003

[36] Majid, I., Nayik, G. A., Dar, S. M. and Nanda, V. (2018). Novel food packaging technologies: Innovations and future prospective. *Journal of the Saudi Society of Agricultural Sciences*, 17(4): 454-462. DOI: https://doi.org/10.1016/j. jssas.2016.11.003

[37] Mascarello, G., Pinto, A., Parise, N., Crovato, S. and Ravarotto, L. (2015). The perception of food quality. Profiling Italian consumers. *Appetite*, 89: 175-182. DOI: https://doi.org/10.1016/j.appet.2015.02.014

[38] Mhurchu, C. N., Eyles, H., Jiang, Y. and Blakely, T. (2018). Do nutrition labels influence healthier food choices? Analysis of label viewing behaviour and subsequent food purchases in a labeling intervention trial. *Appetite*, 12: 360-365. DOI: https://doi. org/10.1016/j.appet.2017.11.105

[39] Misra, N. N., Koubaa, M., Roohinejad, S., Juliano, P., Alpas, H., Inacio, R.S., Saraiva, J.A. and Barba, F.J. (2017). Landmarks in the historical development of twenty first century food processing technologies. *Food Research International*, 97: 318-339. DOI: https://doi.org/10.1016/j.foodres.2017.05.001

[40] Moreb, N. A., Priyadarshini, A. and Jaiswal, A. K. (2017). Knowledge of food safety and food handling practices amongst food handlers in the Republic of Ireland. *Food Control*, 80: 341-349. DOI: https://doi.org/10.1016/j.food cont.2017.05.020

[41] Moslehpour, M., Aulia, C. K. and Masarie, C. E. (2015). Bakery product perception and purchase intention of Indonesian consumers in Taiwan. *International Journal of Business and Information*, 10(1): 63-94. URL: https://api. semanticscholar.org/Corpus ID:55102767

[42] Musaiger, O. A. (2014). Consumption, health attitudes and perception towards fast food among Arab consumers in Kuwait: Gender differences. *Global journal of health Science*, 6(6): 136-143. DOI: https://doi.org/10.5539/gjhs.v6n6p 136

[43] Muthén, B. and Kaplan, D. (1985). A comparison of some methodologies for the factor analysis of non-normal likert variables. *British Journal of Mathematical and Statistical Psychology*, 38: 171-189. DOI: https://doi.org/10.1111/j.20 44-8317.1985.tb00832.x

[44] Nagyová, Ľ., Rovný, P., Stávková, J., Uličná, M. and Maďarová, Ľ. (2014). Consumer perception of bread quality. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis*, 57(3): 115-122. DOI: 10.11118/actaun20095 7030115

[45] Namin, A., Ratchford, B. T., Saint Clair, J. K., Bui, M. and Hamilton, M. L. (2020). Dine-in or take-out: Modeling millennials' cooking motivation and choice. *Journal of Retailing and Consumer Services*, 53: 101981. DOI: https:// doi.org/10.1016/j.jretconser .2019.101981

[46] Ojha, K. S., Kerry, J. P., Duffy, G., Beresford, T. and Tiwari, B.K. (2015). Technological advances for enhancing quality and safety of fermented meat products. *Trends in Food Science & Technology*, 44(1): 105-116. DOI: https:// doi.org/10.1016/ j.tifs.2015.03.010

[47] Olusegun, T. A., Olufemi, O. A., Olaniran, O., Olusola, A., Bolade, K. O. and Oluwatoyosi, O. (2015). Safety of bread for human consumption in an urban community in Southwestern Nigeria. *African Journal of Food Science*, 9(5): 272-277. DOI: https://doi.org/10.5897/AJFS2015.1281

[48] Omari, R. and Frempong, G. (2015). Food safety concerns of fast food consumers in urban Ghana. *Appetite*, 98: 49-54. DOI: https://doi.org/10.1016/j.appet.2015.12.007

[49] Priyadarshini, V. (2015). Purchasing practice of the consumers towards ready to eat food products. *Asian Journal of Home Science*, 10(2): 290-295. URL: http://researchjo urnal.co.in/upload/assignments/10_290-295.pdf

[50] Research and Market (2020). "Market Report – 2020", *https://www.researchandmarkets.com /reports/* (Accessed on 1 Dec, 2020).

[51] Rezai, G., Teng, P. K., Mohamed, Z. and Shamsudin, M. N. (2014). Structural equation modeling of consumer purchase intention toward synthetic functional foods. *Journal of Food Products Marketing*, 20(1): 13-34. DOI: https:// doi.org/10.1080/10454446.2014.9 21868

[52] Sajdakowska, M., Gębski, J., Jeżewska-Zychowicz, M. and Królak, M. (2020). Consumer Choices in the Bread Market: The Importance of Fiber in Consumer Decisions. *Nutrients*, 13(1): 132. DOI: https://doi.org/10.3390/nu13010 132

[53] Sajdakowska, M., Gębski, J., Żakowska-Biemans, S. and Jeżewska-Zychowicz, M. (2019). Willingness to eat bread with health benefits: habits, taste and health in bread choice. *Public Health*, 167: 78-87. DOI: https://doi.org/10.1016/ j.puhe.2018.10.018

[54] Singh, A. and Kathuria, L. M. (2016). Understanding drivers of branded food choice among low-income consumers. *Food Quality and Preference*, 52: 52-61. DOI: https:// doi.org/10.1016/j.foodqual.2016.03.013

[55] Skorepa, L. and Picha, K. (2016). Factors of Purchase of Bread-Prospect to Regain the Market Share?. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis*, 64(3): 1067-1072. DOI: http://dx.doi.org/10.11118 /actaun201664031067

[56] Soon, J. M. (2018). Structural modeling of food allergen knowledge, attitude and practices among consumers in Malaysia. *Food Research International*, 111: 674-681. DOI: https://doi.org/10.1016/j.foodres.2018.06.001

[57] The Research Advisors (2006). Sample Size Table. *Available online - www.research-advisors com/tools/2006*.

[58] Tikkanen, I. and Vääriskoski, M. (2010). Attributes and benefits of branded bread: case Artesaani. *British Food Journal*, 112(9): 1033-1043. DOI: https:// doi.org/10.1108/000 70701011074381

[59] Vlaeminck, P., Jiang, T. and Vranken, L. (2014). Food labeling and eco-friendly consumption: Experimental evidence from a Belgian supermarket. *Ecological Economics*, 108: 180-190. DOI: https://doi.org/10.1016/j.ecolecon.2014.10.01 9

[60] Wambugu, H. W. and Musyoka, R. (2022). Factors influencing behavior of bread consumers in Kenya. *International Journal of Managerial Studies and Research*, 10(2): 1-7. DOI: 10.20431/2349-0349.1002001

[61] Wyrwa, J. and Barska, A. (2017). Packaging as a source of information about food products. *Procedia Engineering*, 182: 770-779. DOI: https://doi.org/10.1016/j.proeng. 2017.03.199.

APPENDIX I
DESCRIPTION OF THE QUESTIONNAIRE

Section 1	**-**	**Convenience**
CONV 1	-	I prefer branded bread because it is easy to cook / prepare.
CONV 2	-	I prefer branded bread because it requires little physical effort to cook and clean.
CONV 3	-	I prefer branded bread because it is easy to store.
CONV 4	-	I prefer branded bread because its waste disposal is easy.
CONV 5	-	I prefer branded bread because it makes life easier.
Section 2	**-**	**Time scarcity**
TS 1	-	I prefer branded bread due to long working hours.
TS 2	-	I prefer branded bread due to busy life style.
TS 3	-	I prefer branded bread due to busy and hectic work schedule.
TS 4	-	I prefer branded bread due to long commuting distance.
TS 5	-	I prefer branded bread because I am always in rush due to time pressure.
Section 3	**-**	**Cooking skills**
CSK 1	-	I prefer branded bread because I have limited knowledge about cooking.
CSK 2	-	I prefer branded bread because I do not know how to cook food from scratch.
CSK 3	-	I prefer branded bread because I can’t match the taste.
CSK 4	-	I prefer branded bread because I did not acquire cooking skills from parents.
Section 4	**-**	**Sensory appeal**
SEN 1	-	I prefer branded bread because it has pleasant appearance.
SEN 2	-	I prefer branded bread because it has good texture.
SEN 3	-	I prefer branded bread because it taste good.
SEN 4	-	I prefer branded bread because it smells nice.
SEN 5	-	I prefer branded bread because it has good flavor.
Section 5	**-**	**Nutritional quality**
QUL 1	-	I prefer branded bread because it is high in mineral content.
QUL 2	-	I prefer branded bread because it is nutritive.
QUL 3	-	I prefer branded bread because it is high in vitamin content.
QUL 4	-	I prefer branded bread because it is in fiber content.

QUL 5	-	I prefer branded bread because it contains natural ingredients.
QUL 6	-	I prefer branded bread because it has necessary quality certification.
Section 6	**-**	**Safety**
SAF 1	-	I prefer branded bread because it contains no hormones.
SAF 2	-	I prefer branded bread because it does not contain any non-permissible colour.
SAF 3	-	I prefer branded bread because it contains no artificial ingredients.
SAF 4	-	I prefer branded bread because it contains no insecticides.
SAF 5	-	I prefer branded bread because it has safety certification.
Section 7	**-**	**Health**
HLT 1	-	I prefer branded bread because it has low calories.
HLT 2	-	I prefer branded bread because it has low fat content.
HLT 3	-	I prefer branded bread because it has low salt content.
HLT 4	-	I prefer branded bread because it has low sugar content.
HLT 5	-	I prefer branded bread because it provides a balanced diet.
Section 8	**-**	**Price**
PRC 1	-	I prefer branded bread because it is not expensive.
PRC 2	-	I prefer branded bread because it is cheaper due to discounted price.
PRC 3	-	I prefer branded bread because it is cheaper due to promotional offer.
PRC 4	-	I prefer branded bread because it is good value for money.
Section 9	**-**	**Product information**
PIF 1	-	I prefer branded bread due to ingredients printed on packaging.
PIF 2	-	I prefer branded bread due to nutritive value printed on packaging.
PIF 3	-	I prefer branded bread due to additives printed on packaging.
PIF 4	-	I prefer branded bread due to certification printed on packaging..
PIF 5	-	I prefer branded bread due to religious belief printed on packaging..
Section 10	**-**	**Processing Technology**
PCT 1	-	I prefer branded bread because processing technology follow international standard.
PCT 2	-	I prefer branded bread because food industry uses cutting edge technology.
PCT 3	-	I prefer branded bread because processing technology is environmental friendly.
PCT 4	-	I prefer branded bread because food industry uses natural ingredients.
PCT 5	-	I prefer branded bread because food industry uses high quality ingredients.
Section 11	**-**	**Packaging**
PKG 1	-	I prefer branded bread due to good quality and appearance of packaging.
PKG 2	-	I prefer branded bread due to convenient shape and size of packaging.
PKG 3	-	I prefer branded bread due to environmental friendly packaging.
PKG 4	-	I prefer branded bread due to advanced packaging technology.
PKG 5	-	I prefer branded bread due to durability of packaging.
Section 12	**-**	**Purchase Intention**
PI 1	-	I will continue to buy branded bread due to competitive price.
PI 2	-	I will continue to buy branded bread due to lack of cooking skills.
PI 3	-	I will continue to buy branded bread due to time scarcity.
PI 4	-	I will continue to buy branded bread due to good quality, safety and healthiness.
PI 5	-	I will continue to buy branded bread because it is easily available and easy to prepare.
PI 6	-	I will continue to buy branded bread as there are choices available.
PI 7	-	I will continue to buy branded bread to reduce environmental damage.
Section 13	**-**	**Consumption**
CON 1	-	I consume branded bread due to convenience.

CON 2	-	I consume branded bread due to good taste, smell and appearance.
CON 3	-	I consume branded bread due to attractive packaging.
CON 4	-	I consume branded bread due to competitive price.
CON 5	-	I consume branded bread due to good quality safety and healthiness.
CON 6	-	I consume branded bread due to my religious and ethical beliefs.
CON 7	-	I consume branded bread due to minimum physical effort to cook / prepare.

Study on various synthetic pesticides and bio-pesticides for managing *Helicoverpa armigera* (Hubbner): Comprehensive Review

Purushottam Arya[1*]; Sundar Singh[2]

[*1]Entomology Lab, Department of Zoology, D.A.V. (P.G.) College, Dehradun, Uttarakhand – INDIA 248001
[*2]Hemvati Nandan Bahuguna Garhwal (A Central) University Srinagar, Uttarakhand - INDIA 246174
*Corresponding Author

Received:- 10 April 2025/ Revised:- 16 April 2025/ Accepted:- 21 April 2025/ Published: 30-04-2025

Abstract— *Helicoverpa armigera Hubbner has been recognized as one of the most significant agricultural pest and causes damage to tomato fruit crops. Globally, India ranks second in tomato production. 8,14,000 hectares of agricultural land utilized for tomato cultivation, with a net productivity of 20.40 million tonnes in 2022-23. Both chemical and biological methods are employed for crop protection. This research examines various pesticides and bio-pesticides, determining their effectiveness based on LC50 values. The study identifies commonly used synthetic and bio-pesticides in farming, including Coragen (Chlorantraniliprole 18.5%), Acrobat (Dimethomorph 50% WP), Indofin M-45 (Mancozeb 75% W/W) and Tandav (Alkaloid: 10%, Benzanine: 12%). The research reveals that Chlorantraniliprole, Spinosad, Indoxacarb, and Emamectin benzoate show notable results in controlling pest infestations. The combination of Thiamethaxim and Chlorantraniliprole demonstrates the highest efficacy in managing pest populations. Bio-pesticides derived from Jatropha, Beauveria bassiana, and Neem seed extract exhibit a high larval mortality rate of 86%. Beauveria bassiana, Bacillus spp., Serratia spp., and Pseudomonas spp. are also effective bio-pesticides. Trichogramma spp. is found to be the parasitoid of Helicoverpa armigera, destroying pest eggs before they hatch and their predator species of pestinclude Chrysopids and ant species such as Pheidole spp. and Iridomyrmex spp. are effective as biological control of tomato fruit borer.*

Keywords— Helicoverpa armigera, Synthetic Pesicides, Bio-Pesticides, Plant-Insect interaction, Chemical control, Bio-control.

I. INTRODUCTION

Vegetables are important food having essential sources of nutrition, providing a wealth of vitamins, minerals, and ions. These crops are cultivated in various settings, including private properties, farmlands, polyhouses, and traded globally. Tomatoes, in particular, play a significant role in Indian cuisine. According to the Indian central government, the country ranked second worldwide in tomato production, yielding 20.40 million tonnes in 2022-23 and total production land is 8,14,000 hectares [1]. However, these fruit and vegetables are susceptible to damage from natural threats such as insect pests, fungi, and microbial infections.

Tomato generation in India is concentrated in a few states, counting Uttar - Pradesh, Madhya-Pradesh, Odisha, Karnataka, Bihar, Punjab, West Bengal, Andhra Pradesh, Jammu and Kashmir, Himachal Pradesh, and Uttarakhand.*Helicoverpa armigera,* which is major pest poses a significant threat to fruits and vegetables. This insect is responsible for substantial crop yield reductions in various plants. This insect poses a significant threat to agriculture and farming due to its polyphagous nature. The growing pest population has led to increased pesticide application, subsequently affecting tomato cultivation costs. Research indicates that the pest has developed resistance to certain pesticides due to their extensive use [2]. This resistance facilitates insect - population growth. Bio-pesticides have shown effectiveness in reducing pest numbers while being environmentally friendly and preserving biodiversity [3], [4]. Additionally, bio-pesticides prevent alterations in soil composition.

The newly brought outlarvae of this insect expend delicate foliage or youthful leaves. As the larvae develop, they enter the natural product and nourish on its insides. This renders the natural product unsuitable for human utilization [5].Various methods are employed to manage this pest, including mechanical, chemical, and biological control. Mechanical control is challenging due to the difficulty in targeting insect eggs, larvae, and pupae across large agricultural areas, and also it is time-consuming. Chemical control is currently used in fruit and vegetable cultivation; however, synthetic pesticides significantly impact soil properties and fruit quality. Bio-pesticides offer a potential replacement for synthetic pesticides without causing harm and promote eco-friendly farming practices.

Biological control is also effective, causing substantial damage to insect pest populations at different life stages through the use of parasitoids and predators. Studies have identified six egg parasitoids from two distinct families, with only Hymenoptera demonstrating significant control of *Helicoverpa armigera* eggs [6]. *Trichogramma spp*. attacks eggs, causing their death before hatching [7],[8]. Research indicates that in India, the most significant predators of pest's are Chrysopids and certain ant species, specifically *Pheidole spp.* and *Iridomyrmex spp.*[9], [10], [11], [12], [13]. Also susceptible to infection by entomopathogenic organisms, including the fungus *Beauveria bassiana, H. armigera* nucleopolyhedrovirus (HaNPV), and the soil bacterium *Bacillus thuringiensis* (Bt) [14],[15]. The pest is known to infest various host crops such as tomatoes, cotton, maize, chickpea, pigeon pea, sorghum, sunflower, soybean, and groundnuts [16],[17], [18].

This study proposes a shift from synthetic synthetic pesticides to the utilization of bio-pesticides and biological agents for insect pest management. The aim is to promote environmentally friendly farming practices, potentially reducing production costs and enhancing crop yields.

II. OBSERVATION

Application of synthetic pesticides in agriculture are most common practice to protect crop yield from pests. Synthetic pesticides are used in different levels of concentration and toxicity. Along with these synthetic pesticides, plant origin pesticides introduce to safe and eco-friendly agricultural practices that decrease the dependency on non-biodegradable or synthetic pesticides. bio-pesticide were use for over 1000 years but in the last centuries synthetic pesticides become a problem because of extensive use of them [19].

Effectively controlling *Helicoverpa armigera* is vital in both agricultural and non- farming settings. Applying suitable and applicable pest control strategies is essential. The most effective styles for managing pest populations involve proper timing and the use of applicable ways for applying synthetic synthetic pesticides and bio-pesticides.

2.1 Synthetic Pesticide:

Various studies have been demonstrated that both chemical and biological methods are employed for agricultural pest control. Synthetic synthetic pesticides are considered the most effective in managing pest infestations, despite some pests developing resistance to certain pesticides. Newer generations of pesticides are being utilised in farming practices. Researchers have conducted laboratory and field experiments to evaluate the efficacy of different pesticides concentrations. Table 1. shows the impact of various pesticides and their concentrations on reducing pest population.

TABLE 1
SYNTHETIC PESTICIDES USED IN VARIOUS RESEARCHES

Sr. No.	Pesticide(s)	Concentration	Outcome	References
1	NSKE 5%	5%	NSKE 5% in okra can decrease the population of *Helicoverpa armigera*.	[20]
2	Emamectin benzoate, Spinosad, *Bacillus thuringiensis*	1.38, 114.09, 54.19	Research indicates Emamectin benzoate shows higher toxicity against *S. littoralis*. Based on LC_{50}, Spinosad and *B. thuringiensis* exhibit less toxicity than Emamectin benzoate, pyrethroid, and Spinetoram.	[21], [22], [23], [24]
3	Deltaphos 360EC, Tracer 240SC, Steward 150EC, Emamectin 1.9SC, Lorsban 40EC, Curacron 500EC	600 ml, 80 ml, 175 ml, 200 ml, 1000 ml, 1000 ml	Tracer 240SC had the highest efficacy, causing 93% mortality in *H. armigera* larvae. Descending effectiveness: Steward 88%, Emamectin 87%, Deltaphos 74%, Lorsban 73%, Curacron 70%.	[25]
4	Cypermethrin, Endosulfan, Monocrotophos, Quinalphos, Methomyl, Fenvalerate, Chlorpyriphos	90% w/w, 94% w/w, 73% w/w, 72% w/w, 73% w/w, 90% w/w, 98% w/w	*H. armigera* has lost resistance to these pesticides.	[26]
5	Chlorantraniliprole, Indoxacarb, Flubendiamide, Spinetoram, Thiamethoxam + Chlorantraniliprole, Fipronil, Emamectin benzoate, Pirate, Lufenuron	100 ml, 175 ml, 50 ml, 60 g, 80 ml, 480 ml, 200 ml, 320 ml, 800 ml	Most effective in descending order: Thiamethoxam+Chlorantraniliprole, Spinetoram, Chlorantraniliprole, Flubendiamide, Indoxacarb. For *H. armigera* in tomato crop, applied per 100 L water.	[27]
6	Emamectin benzoate 5SG, Flubendiamide 20WG, Chlorantraniliprole 20SC, Thiodicarb 75% WP, Indoxacarb 14.5SC, Novaluron 10EC	250 g/ha, 150 ml/ha, 150 ml/ha, 500 g/ha, 500 ml/ha, 500 ml/ha	Chlorantraniliprole 20SC was most effective, reducing infestation from 82.81% to 74.2% in tomatoes during Kharif.	[28]
7	Indoxacarb 14.5% SC, Flubendiamide 39.5% SC, Novaluron 10% EC, Fipronil 5% SC, Spinosad 45% SC, Neem oil 0.03%, Emamectin benzoate 5% SG	Manufacturer-recommended doses	Spinosad was most effective against *H. armigera*. Neem oil was least effective.	[29], [30]
8	Spinosad 2.5% SC, Indoxacarb 14.5% SC, Emamectin benzoate 5% SG, Flubendiamide 20% WDG, Chlorfenapyr 10% SC, Novaluron 10% EC, Chlorantraniliprole 8.5% SC, Azadirachtin 3000 ppm, Quinalphos 25% EC, Acephate 75% SP	0.0020, 0.0075, 0.001, 0.005, 0.0075, 0.0075, 0.006, 0.0006, 0.03, 0.05	Toxicity order: Quinalphos > Azadirachtin > Novaluron > Acephate. Least effective: Flubendiamide, Chlorantraniliprole, Emamectin.	[31]

9	Imidacloprid 17.8SL, Fipronil 5SC, Nemarin (Neem Oil) 1500 ppm, Indoxacarb 14.5SC, Malathion 50EC, Spinosad 45SC	0.50 ml, 1.0 ml, 3.0 ml, 1.0 ml, 1.0 ml, 0.20 ml	Indoxacarb most toxic, reducing infestation by 85.4%. Followed by Fipronil (81.78%), Malathion (79.04%), Imidacloprid (75.62%), Spinosad (72.51%), Neemarin (68.05%).	[32]
10	Flubendiamide 39.35% SC, Quinalphos 25% EC	150 ml/ha	Flubendiamide 39.35% SC was found effective against *H. armigera*.	[33]
11	Profenofos 50EC, Novaluron 10% EC, Imidacloprid 17.8 SL, Fipronil 50SC, Indoxacarb 14.5SC	0.05%, 0.01%, 0.03%, 0.005%, 0.014%	Indoxacarb 14.5SC showed maximum effectiveness across all treatments.	[34]
12	K-OPTIMAL 35EC, SAUVEUR 62EC	Manufacturer-recommended doses	K-OPTIMAL 35EC was more effective than SAUVEUR 62EC.	[35]
13	Emamectin benzoate, Spinetoram, Flubendiamide, Broflanilide	10 mg/L to 40 mg/L, 10 µl/L to 40 µl/L, 1.0 g/L to 4.0 g/L, 10 µg/L to 40 µg/L	Flubendiamide and Spinetoram were less effective than Emamectin and Broflanilide, which showed higher toxicity.	[36]
14	Indoxacarb 14.5% SC, Chlorantraniliprole 18.5% SC, Cyantraniliprole 10.26% OD	0.8 ml/L, 0.25 ml/L, 1.2 ml/L	All treatments were effective in controlling insect infestation.	[37]

The literature reports multiple pesticides under diverse studies. Table 1(a) provides a summary of all pesticides investigated in the studies.

TABLE 1 (a)
LIST OF PESTICIDES (FROM TABLE 1) USED IN RESEARCH AND AGRICULTURAL PRACTICES

Synthetic Pesticide	Synthetic Pesticide	Synthetic Pesticide	Synthetic Pesticide
Acephate 75% SP	Curacron 500EC (1000 ml)	Imidacloprid 17.8 SL	Pirate
Azadirachtin 3000 ppm	Deltaphos 360EC (600 ml)	Indoxacarb	Quinalphos
Bacillus thuringiensis	Emamectin 1.9SC (200 ml)	K-OPTIMAL 35EC	Spinetoram
Broflanilide	Emamectin benzoate 5% SG	Lorsban 40EC (1000 ml)	Profenofos 50EC
Chlorantraniliprole	Endosulfan	Lufenuron	Quinalphos 25% EC
Chlorantraniliprole 8.5% SC	Fenvalerate	Malathion 50EC	SAUVEUR 62EC
Chlorantraniliprole 18.5% SC	Fipronil 5% SC	Methomyl	Spinosad 2.5% SC
Chlorantraniliprole 20SC	Flubendamide	Monocrotophos	Steward 150EC (175 ml)
Chlorfenapyr 10% SC	Flubendiamide 20% WDG	Neem oil 0.03%	Thiamethoxam
Cyantraniliprole 10.26% OD	Flubendiamide 39.35% SC	Novaluron 10% EC	Thiodicarb 75% WP
Cypermethrin	Gronim 0.03%	NSKE 5%	Tracer 240SC (80 ml)

Based on research findings, scientists have determined that Spinosad, Chlorantraniliprole, Indoxacarb, and Emamectin benzoate shows significant results in controlling *Helicoverpa armigera* populations in fruit and vegetable cultivation. These pesticides demonstrate superior effectiveness compared to other pesticides. Numerous studies have identified Chlorantraniliprole as particularly effective in managing pest populations in tomato crops, ranking it as the top-performing pesticide. Indoxacarb has shown a high mortality rate of 93% against *Helicoverpa armigera* and can significantly reduce pest infestations. Emamectin benzoate has been reported to have higher toxicity than Spinosad and *Bacillus thuringiensis*. Flubendiamide exhibits varying levels of effectiveness at higher concentrations. The combination of Thiamethaxim and Chlorantraniliprole demonstrates greater efficacy compared to individual pesticide applications.Research indicates that *Helicoverpa armigera* is becoming more susceptible to certain pesticides, including Endosulfan, Monocrotophos, and

Quinalphos. Multiple studies emphasize the importance of pesticide concentration and dosage, as effectiveness is dependent on varying concentration levels. The LC50 value is crucial in determining pesticide toxicity.

2.2 Bio-Pesticides:

In addition to synthetic pesticides, bio-pesticides offer an effective alternative for controlling *Helicoverpa armigera* and can potentially replace synthetic pesticide. Research has been conducted on various plants with pesticidal, microbial, and fungal repellent properties. The extracts and crude oils from these plants can help manage insect pest infestations. *Table 2* presents different plant-based pesticides and their efficacy as demonstrated in various experimental studies.

TABLE 2
BIO-PESTICIDES

Sr. No.	Bio-Pesticide	Concentration	Outcome	Reference
1	*Lantana camara* leaf extract	0.5%, 1.0%, 2.5%, 5.0%	Mortality rate increased with dosage. Morphological abnormalities such as failure to pupate and deformed adults with darkened wings observed.	[38], [39]
2	*Beauveria bassiana*, Metarhizium anisopliae EPN, Sweet flag rhizome oil (*Acorus calamus*), Clove oil (*Syzygium aromaticum*), Custard apple (*Annona squamosa*) leaf extract	5% each	*B. bassiana* showed highest toxicity; clove oil had minimal effect.	[40]–[47]
3	Plant extracts: *Annona*, *Chrysanthemum*, *Datura*, *Jatropha*, *Neem*, *Parthenium*, *Pongamia*, *Tridax*, *Vitex* PGPR: *Bacillus subtilis*, *B. megaterium*, *Serratia marcescens*, *Pseudomonas spp.* Fungus: Metarhizium anisopliae	1%	Larval mortality ranged 42–86%. *Jatropha* (86%) most effective, followed by *Pongamia* (76%), *Neem* (71%). Significant weight reduction with *Vitex* (71%). Effective against *H. armigera* and *S. litura*.	[48]
4	Neem seed, Turmeric, Garlic, Henge crude extracts, Thiodan	2.5%, 3.5%, 5%, 2.5%, 0.07% respectively	Neem seed extract showed the highest effectiveness compared to others.	[49]
5	Eucalyptus (*E. tereticornis*), Bakayan (*Melia azedarach*), Chilli (*Capsicum annum*), Thyme (*Thymus vulgaris*), Onion (*Allium cepa*)	5% each	*Eucalyptus*, *Chilli*, and *Onion* extracts were most effective against *H. armigera*.	[29]
6	Neem seed, Turmeric, Garlic, Marsh Pepper	10%	Neem seed extract was the most effective compared to garlic and marsh pepper.	[50]
7	Lemongrass oil, Neem oil, Garlic bulb, Ginger rhizome, Artemisia leaf extract	1%, 1%, 5%, 5%, 5% respectively	All were effective against *H. armigera*. Ginger rhizome was least effective.	[51]
8	Bitter melon leaves (*M. charantia*), Galangal leaves (*L. indica*), Agrestic adjuvant	1.16%–2.92%	Extracts reduced pest feeding efficiency and digestive capacity.	[52]
9	*Withania somnifera* ethanolic extract	1.33%	Induced mortality in 3rd instar larvae after 48 hrs. Observed lethargy, feeding reduction, extended larval period. LC_{50} = 1.33%.	[53]
10	*Beauveria bassiana* spores, Neem (*Azadirachta indica*), Garlic (*Allium sativum*)	5% each	Reduced feeding: 80% in 3rd instar, 55% in 1st instar, 35% in 5th instar larvae.	[54]

Table 2(a) provides an overview of bio-pesticides, while table 2(b) outlines microbial and fungal repellents.

TABLE 2 (a)
PLANT EXTRACTS

Annona	Datura	Lemon grass oil	Pongamia
Artemisia leaf extract	Eucalyptus (*Eucalyptus tereticornis*)	Neem	Tridax
Bakayan (*Melia azedarach*)	Garlic bulb extract	Neem oil (Seed Extract)	Thyme (*Thymus vulgaris*)
Chilli (*Capsicum annum*)	Ginger rhizome extract	Onion (*Allium cepa*)	Vitex
Chrysanthemum	*Lantana camara* leaf extract	Parthenium	*Withania somnifera* extract
Henge			

TABLE 2 (b)
MICROBIAL AND FUNGAL REPELLENTS

Beauveria bassiana
EPN (*Entomopathogenic Nematodes*)
Metarhizium anisopliae
Plant Development Advancing Microbes: *Bacillus spp.*, *Serratia spp.*, and *Pseudomonas spp.*
Biowash

The Jatropha, *Beauveria bassiana*, and Neem seed extract demonstrated superior effectiveness in controlling *Helicoverpa armigera* infestations in tomato crops, achieving 86% larval mortality rate. Ginger rhizome, clove oil, marsh pepper, and garlic proved to be the least effective in managing the pest. These bio-pesticides are environmentally friendly and safe for agricultural use, making them viable alternatives to synthetic pesticides.

2.3 Life cycle:

The tomato fruit borer undergoes four life stages: egg, larva, pupa, and adult. This insect's lifespan ranges from 4 to 12 weeks, typically occurring between early March and late June in summer. The winter phases generally require more time to complete. A female fruit borer can produce up to 1000 eggs, which hatch within 3 to 11 days. Upon hatching, the larvae emerge and progress through seven developmental stages (Instars), over a period of 19 to 36 days. Following the larval stage, the insect enters the pupal phase, which lasts 13 to 15 days. The final adult stage of the fruit borer has a duration of approximately 8 to 10 days [55], [56].

III. CONCLUSION

Helicoverpa armigera has been reported important insect pest. Studies carried out over the world to control infestation with the help of synthetic pesticides and bio-pesticides. The Spinosad, combination of Thiamethaxim and Chlorantraniliprole demonstrates the highest efficacy in managing pest populations. Chlorantraniliprole, Indoxacarb and Emamectin benzoate also have the advanced usesin delving and farming practices. Bio-pesticides like Jatropha, Eucalyptus (*Eucalyptus tereticornis*), Neem oil (Seed Extract), Chilli (*Capsicum annum*), *Beauveria bassiana*, *Bacillus spp.*, *Serratia spp.* and *Pseudomonas spp are* also effective. *Trichogramma spp.* is found to be the most effective parasitoid and predators are Chrysopids and ant species such as *Pheidole spp.* and *Iridomyrmex spp.* effective tocontrol insect population of *Helicoverpa armigera (Hub.).*

REFERENCES

[1] S. P. Singh, R. K. Dwivedi, and K. Kishor, "Population dynamics of tomato fruit borer *Helicoverpa armigera* Hubner in relation to abiotic factors in central U.P.,"*The Pharma Innovation J.*, vol. SP-10, no. 11, pp. 39–43, 2021.

[2] A. Sharma, R. Raina, R. Kapoor, and K. S. Thakur, "Eco-friendly management of tobacco caterpillar with pheromone traps and *Bacillus thuringiensis* var. kurstaki in Chamba district of Himachal Pradesh, India,"*J. Ent. Res.*, vol. 44, no. 4, pp. 523–528, 2020. DOI: 10.5958/0974-4576.2020.00088.2.

[3] T. H. Basedow, H. R. Ossiewatsch, J. A. Bernal Vega, S. Kollman, H. Elshafie, and C. M. Y. Nicol, "Control of aphids and whiteflies (Homoptera, Aphididae and Aleyrodidae) with different neem preparations in laboratory, greenhouse and field: effects and limitations,"*Journal of Plant Disease & Protection*, vol. 109, pp. 612-623, 2002.

[4] H. A. F. El Shafie and T. Basedow, "The efficacy of different neem preparations for the control of insects damaging potatoes and eggplants in Sudan,"*Crop Protection*, vol. 22, pp. 1015-1021, 2003.

[5] L. Li, T.-C. Shen, Y. Chen, and Shih Ying Hwang, "Responses of *Helicoverpa armigera* to Tomato Plants Previously Infected by ToMV or Damaged by *H. armigera*," *Journal of Chemical Ecology*, vol. 34, no. 3, pp. 353–361, Feb. 2008, doi: https://doi.org/10.1007/s10886-008-9439-x.

[6] J. Romeis, T. G. Shanower, and K. N. S. Jyothirmayi, "Constraints on the use of *Trichogramma* egg parasitoids in biological control programmes in India,"*Biocontrol Sci. Technol*., vol. 8, pp. 289–299, 1998.

[7] T. B. C. Alavo, "Biological control agents and environmentally-friendly compounds for the integrated management of *Helicoverpa armigera* Hubner (Lepidoptera: Noctuidae) on cotton: Perspectives for pyrethroid resistance management in West Africa?,"*Archives of Phytopathology and Plant Protection*, vol. 39, no. 2, pp. 105–111, Apr. 2006.

[8] F. P. Pereira, C. Reigada, A. J. F. Diniz, and J. R. P. Parra, "Potential of two Trichogrammatidae species for *Helicoverpa armigera* control,"*Sociedade Entomológica do Brasil*, 2019, doi: 10.1007/s13744-019-00730-4.

[9] H. V. D. Berg and M. J. W. Cock, "Exclusion cage studies on the impact of predation on *Helicoverpa armigera* in cotton,"*Biocontrol Science and Technology*, vol. 3, no. 4, pp. 491-497, 1993.

[10] H. V. D. Berg and M. J. W. Cock, "Natural control of *Helicoverpa armigera* in cotton: Assessment of the role of predation,"*Biocontrol Science and Technology*, vol. 5, pp. 453-463, 1995.

[11] H. V. D. Berg, M. J. W. Cock, and G. I. Oduor, "Natural control of *Helicoverpa armigera* in sunflower: Assessment of the role of predation,"*Biocontrol Science and Technology*, vol. 7, pp. 613-629, 1997.

[12] J. Romeis and T. G. Shanower, "Arthropod natural enemies of *Helicoverpa armigera* (Hubner) (Lepidoptera: Noctuidae) in India,"*Biocontrol Sci. Technol*., vol. 6, pp. 481–508, 1996.

[13] S. Mansfield, N. V. Elias, and J. A. Lytton-Hitchins, "Ants as egg predators of *Helicoverpa armigera* (Hubner) (Lepidoptera: Noctuidae) in Australian cotton crops,"*Austral Journal of Entomology*, vol. 42, pp. 349–351, 2003.

[14] S. S. Sandhu, R. C. Rajak, and G. P. Agarwal, "Studies of prolonged storage of *Beauveria bassiana conidia*: Effects of temperature and relative humidity on conidial viability and virulence against chickpea borer, *Helicoverpa armigera*,"*Biocontrol Sci. Technol*., vol. 3, no. 1, pp. 47–53, 1993.

[15] B. C. G. Scholz, C. J. Monsour, and M. P. Zalucki, "An evaluation of selective *Helicoverpa armigera* control options in sweet corn,"*Austral. J. Exp. Agric.*, vol. 38, pp. 601–607, 1998.

[16] J. P. Cunningham, M. P. Zalucki, and S. A. West, "Learning in *Helicoverpa armigera* (Lepidoptera: Noctuidae): A new look at the behaviour and control of a polyphagous pest,"*Bulletin of Entomological Research*, vol. 89, pp. 201-207, 1999.

[17] K. R. Kranthi, S. Kranthi, and R. R. Wanjari, "Baseline toxicity of Cry1A toxins to *Helicoverpa armigera* (Hubner) [Lepidoptera: Noctuidae] in India,"*International Journal of Pest Management*, vol. 47, no. 2, pp. 141–145, 2001.

[18] S. S. Mahapatra, B. K. Sahoo, and B. Kariyanna, "Evaluate the efficacy of eco-friendly pesticides against the lepidopteran pests,"*International Journal of Chemical Studies*, vol. 6, pp. 1795-1798, 2018.

[19] S. Bobate, P. Bokade, and A. Bajaj, "Engineered yeasts as biocatalysts for pesticide degradation,"*Advances in Yeast Biotechnology for Biofuels and Sustainability*, Elsevier, pp. 449-474, 2023. DOI: 10.1016/B978-0-323-95449-5.00015-1.

[20] B. S. T. Rao, G. P. V. Reddy, M. M. K. Murthy, and V. D. Prasad, "Efficacy of neem products in the control of bhendi pest complex,"*Indian Journal of Plant Protection*, vol. 19, pp. 49-52, 1991.

[21] S. J. Duffield and S. L. Jordan, "Evaluation of synthetic pesticides for the control of *Helicoverpa armigera* (Hübner) and *Helicoverpa punctigera* (Wallengren) (Lepidoptera: Noctuidae) on soybean, and the implications for field adoption,"*Australian Journal of Entomology*, vol. 39, pp. 322–327, 2000.

[22] A. A. El-Moursy, E. A. Kares, N. Zohdy, A. M. Abdel-Rahman, and M. B. R. El Mandarawy, "Effect of *Bacillus thuringiensis* Berliner, a chemical synthetic pesticide and its mixtures against unparasitized and parasitized *Spodoptera littoralis* (Boisd.) larvae,"*Egyptian Journal of Agricultural Research*, vol. 78, no. 4, pp. 1587-1601, 2000.

[23] J. B. A. El-Naggar, "Sublethal effect of certain synthetic pesticides on biological and physiological aspects of *Spodoptera littoralis* (Boisd.),"*Natural and Science*, vol. 11, no. 7, pp. 19-25, 2013.

[24] S. M. S. Badr and N. M. Faiz, "Toxicological and Physiological Impacts of Some Insecticides on the Cotton Leafworm, *Spodoptera littoralis* (Boisd.) (Lepidoptera: Noctuidae),"*Journal of Plant Protection and Pathology, Mansoura University*, vol. 15, no. 10, pp. 355-358, 2024.

[25] M. TariqCh. and M. A. M. N. Iqbal, "Management of *Helicoverpa armigera* with different synthetic pesticides,"*Pak. J. Agri. Sci.*, vol. 42, no. 1–2, 2005.

[26] I. Chaturvedi, "Status of Insecticide Resistance In The Cotton Bollworm, *Helicoverpa armigera* (Hubner),"*Journal of Central European Agriculture*, vol. 8, no. 2, pp. 171-182, 2007.

[27] G. Abbas, N. Hassan, M. Farhan, I. Haq, and H. Karar, "Effect of Selected Insecticides on *Helicoverpa armigera* Hubner (Lepidoptera: Noctuidae) on Tomato (*Lycopersicon esculentum* Miller) and Their Successful Management,"*Advances in Entomology*, vol. 3, pp. 16-23, 2015. DOI: 10.4236/ae.2015.31003.

[28] D. S. Rani, S. P. Kumar, M. N. Venkatesh, C. H. N. Satya Sri, and K. A. Kumar, "Bio-efficacy of synthetic pesticides against gram pod borer, *Helicoverpa armigera* in red gram,"*Journal of Entomology and Zoology Studies*, vol. 6, no. 2, pp. 3173-3176, 2018.

[29] A. Usman, M. I. Ali, M. Shah, Fazal-e-Amin, and J. Sarwar, "Comparative efficacy of indigenous plant extracts and a synthetic synthetic pesticide for the management of tomato fruit worm (*Helicoverpa armigera* Hub.) and their effect on natural enemies in tomato crop,"*Bolan Soc. Pure Appl. Biol.*, vol. 7, no. 3, pp. 1014–1020, 2018. DOI: 10.19045/bspab.2018.700120.

[30] C. Manisha and A. Kumar, "Field efficacy and economics of different synthetic pesticides against tomato fruit borer [*Helicoverpa armigera* (Hubner)],"*International Journal of Plant & Soil Science*, vol. 34, no. 22, pp. 455-460, 2022.

[31] S. Patel, H. V. Pandya, and S. P. Saxena, "Bio-efficacy of synthetic pesticides and neem products against *Helicoverpa armigera*(Hubner) on tomato,"*Journal of Entomology and Zoology Studies*, vol. 7, no. 4, pp. 1302-1305, 2019.

[32] S. Kumar, R. S. Umrao, A. Kumar, V. K. Patel, R. Debnath, and A. Kumar, "Evaluation of the efficacy of synthetic pesticides and bio-pesticides against *Helicoverpa armigera* (Hubner) on tomato,"*Journal of Entomology and Zoology Studies*, vol. 8, no. 3, pp. 555-558, 2020.

[33] M. D. Choudhary, A. S. Jat, G. C. Singh, and S. D. Bamboriya, "Bio efficacy of novel synthetic pesticide against chickpea pod borer, *Helicoverpa armigera* (Hubner),"*The Journal of Rural and Agricultural Research*, vol. 23, no. 1, pp. 42-44, 2023.

[34] B. Rathour and S. Ravi, "In vivo appraisal of phytoextracts, essential oils and synthetic pesticides against tomato fruit borer (*Helicoverpa armigera* Hubner),"*Indian Journal of Hill Farming*, vol. 36, no. 1, pp. 167-171, June 2023.

[35] D. Dohouonan, F. Drissa, D. Y. K. Séraphin, A. A. A. Moïse, and T. Yao, "Efficacy of two pesticides against *Helicoverpa Armigera* (Lepidoptera: Noctuidae) found on tomato plants in the Bafing region, Touba, Côte d'Ivoire,"*International Journal of Entomology Research*, vol. 9, no. 6, pp. 138-142, 2024.

[36] V. K. Srivastava, A. Tripathi, and A. C. Dwivedi, "Investigation on in-vitro bioassay for dose optimisation of different synthetic pesticides against *Helicoverpa armigera* (Hubner),"*J. Nehru Gram Bharati Univ.*, vol. 13, no. 1, pp. 42–54, 2024.

[37] Raghuvendra K.V., Rekha Balodi and Subhash chander -ICAR-National Research Centre for Integrated Pest Management, 2023

[38] S. T. Narendran, S. Arivoli, and S. Ignacimuthu, "Evaluation of larvicidal and antifeedant activity of two plants," in Proceedings of Bio-Pesticides in Insect Pest Management, Phoenix Publishers, New Delhi, pp. 152-155, 1990.

[39] M. Singh, J. H. Naik, H. Pande, and B. R. Kaushal, "Biological effects of a plant extract on gram pod borer, *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae),"*J. Env. Bio-Sci.*, vol. 33, no. 1, pp. 177–183, 2019.

[40] V. Kumar and P. Chowdhry, "Virulence of entomopathogenic fungi *Beauveria bassiana* and *Metarhizium anisopliae*against tomato fruit borer, *Helicoverpa armigera*,"*Indian Phytopathology*, vol. 57, no. 2, pp. 208-212, 2004.

[41] S. Subramaniam and S. Kaushik, "Cryptic but some potential Insecticidal Plants of India," *Journal of Medicinal Plants Studies*, Vol. 2, No. 3, pp. 44-50, 2014.

[42] V. Kalia, G. Sharma, D. I. Shapiro-Ilan, and S. Ganguly, "Biocontrol potential of *Steinernema thermophilum* and its symbiont Xenorhabdus indica against lepidopteran pests: Virulence to egg and larval stages,"*Journal of Nematology*, vol. 46, no. 1, pp. 18-26, 2014.

[43] P. Savita, B. M. Adsure, and Pandurang, "Efficacy of entomopathogenic fungi against gram pod borer, *Helicoverpa armigera* (Hub.) on chickpea,"*J. Global Biosci*., vol. 4, no. 8, pp. 3154–3157, 2015.

[44] D. Melani, T. Himawan, and A. Afandhi, "Bioactivity of sweet flag (*Acorus calamus* Linnaeus) essential oils against *Spodoptera litura* Fabricius (Lepidoptera: Noctuidae),"*Journal of Tropical Life Science*, vol. 6, no. 2, pp. 86-90, 2016.

[45] K. M. Ajaykumara andR. Tiwar, "Field Efficacy of Plant Leaf Extracts against *Helicoverpa armigera*(Hubner) on Chickpea at Pantnagar, Uttarakhand."*International Journal Pure Applied Bioscience*. SPI: 2018;6(1):6-13. ISSN: 2320 – 7051.

[46] X. Gong and R. Yujian, "Larvicidal and ovicidal activity of carvacrol, p-cymene, and γ-terpinene from Origanum vulgare essential oil against the cotton bollworm, *Helicoverpa armigera* (Hübner),"*Environmental Science and Pollution Research*, vol. 27, no. 15, pp. 18708-18716, 2020.

[47] M. Kammara, S. Simon, and S. Dasika, "Comparative efficacy of bio-agents and botanical extracts against *Helicoverpa armigera* (Hubner) on chickpea (Cicer arietinum L.) crop,"*The Pharma Innovation Journal*, vol. SP-11, no. 6, pp. 160-166, 2022.

[48] S. Gopalakrishnan, "Efficacy of botanical extracts and entomopathogens on control of *Helicoverpa armigera* and *Spodoptera litura*," African Journal of Biotechnology, vol. 10, 2011, doi: 10.5897/AJB11.2475.

[49] J. A. Shah, M. Inayatullah, K. Sohail, S. F. Shah, S. Shah, T. Iqbal, and M. Usman, "Efficacy of botanical extracts and a chemical pesticide against tomato fruit worm, *Helicoverpa armigera*,"*Sarhad J. Agric.*, vol. 29, no. 1, 2013.

[50] S. Ali, Y. Li, I. U. Haq, W. Abbas, M. Z. Shabbir, and M. M. Khan, "The impact of different plant extracts on population suppression of *Helicoverpa armigera* (Hub.) and tomato (*Lycopersicon esculentum* Mill) yield under field conditions,"*PLoS ONE*, vol. 16, no. 12, 2021. DOI: 10.1371/journal.pone.0260470.

[51] B. Rathour and S. Ravi, "In vivo appraisal of phytoextracts, essential oils and synthetic pesticides against tomato fruit borer (*Helicoverpa armigera* Hubner),"*Indian Journal of Hill Farming*, vol. 36, no. 1, pp. 167-171, June 2023.

[52] Nursal and A. H. Jhon, "Feeding activity of *Heliotis armigera* Hubner larvae on food formulated with ethanol extracts of bitter melon leaves (*Momordica charantia* L.), galangal leaves (Lactuna indica L.), and adjuvant Agrestic,"*International Journal of Ecophysiology*, vol. 6, no. 1, pp. 58-63, 2024.

[53] Y. Ohadi, R. Azizi, and J. J. Sendi, "The toxic effects of winter cherry on the physiology of cotton bollworm *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae),"*Entomological Society of Iran*, vol. 44, no. 3, pp. 239-255, 2024, doi: 10.61186/jesi.44.3.1.

[54] V. Mishra and S. Modi, "Comparative analysis of the mechanisms of action of *Beauveria bassiana* and botanical synthetic pesticides against *Helicoverpa armigera*,"*African Journal of Biomedical Research*, vol. 27, no. 3S, pp. 3748-3757, Oct. 2024, doi: 10.53555/AJBR.v27i3S.3035.

[55] A. A. Baikar and K. V. Naik, "Biology of Fruit Borer, *Helicoverpa Armigera* (Hubner) on Chilli Under Laboratory Conditions,"*Plant Archives*, vol. 16, no. 2, pp. 761-769, 2016.

[56] K. P. Herald and A. R. Tayde, "Biology and morphology of tomato fruit borer, *Helicoverpa armigera* (Hubner) under Allahabad Conditions,"*Journal of Entomology and Zoology Studies*, vol. 6, no. 4, pp. 1734-1737, 2018

Utilization of Agro Wastes into Animal Feed through Solid-State Fermentation

Marsela Dalyna Rosly[1*], Lee Kui Soon[2]

Faculty of Resources Science and Technology, University Malaysia Sarawak, Malaysia
*Corresponding Author

Received:- 11 April 2025/ Revised:- 18 April 2025/ Accepted:- 26 April 2025/ Published: 30-04-2025

Abstract— *The regions of Southeast Asia generate significant quantities of underused agro-industrial residues that include sago hampas and rice bran and palm kernel cake (PKC) and cassava peels while these materials hold substantial nutritional value. This review is prepared in accordance with PRISMA guidelines examines current research (2015–2025) about transforming agricultural leftovers into improved animal feed through solid-state fermentation (SSF). Thirty-three relevant studies examined microorganisms such as Aspergillus, Trichoderma and Bacillus and lactic acid bacteria together with fermentation conditions that improved animal nutritional quality alongside performance outcomes. During SSF the protein content increased by up to 30–35% in PKC while fiber fractions decreased specifically cellulose and hemicellulose and anti-nutrient effects were observed with cyanogenic glycosides and phytates reduction. The study identified fermented PKC together with rice bran as protein concentration feeds which benefit both monogastric and ruminant animals and fermented cassava peels alongside sago hampas function as digestible energy sources through supplementary nitrogen use. The fermentation process through SSF led to various co-benefits which improved digestive capacities and gut health together with elevated feed conversion for poultry, swine, fish and ruminant livestock. The utilization of SSF faces ongoing operational hurdles because fermentation needs scale-up alongside microbial safety controls and feed maintenance stability. The sustainability solution of SSF meets circular agriculture's criteria through waste transformation for animal feed production while decreasing imported ingredient use and protecting the environment. The research evidence indicates that implementing SSF technology throughout Southeast Asia requires government backing together with staff training sessions and the establishment of scalable technological solutions to support broader adoption.*

Keywords— Agro-industrial Waste, Animal Feed, Protein Enrichment, Sago Hampas, Solid-State Fermentation (SSF).

I. INTRODUCTION

Extensive crop production in Southeast Asia yields huge amounts of agro-industrial residues (agro-wastes) [1]. Some of the common examples include sago hampas (the fibrous by-product of the pith after sago starch extraction), rice bran (a by-product of rice milling), palm kernel cake (PKC, a by-product of palm oil extraction), and cassava peels [2]. Such materials, which are often discarded or underutilized, have significant nutrients. For example, palm kernel cake offers 14–18% and 12–20% crude protein (CP) and crude fiber (CF), whereas cassava peels also offer only ~4–6% CP but are high in fibre (≈34% hemicellulose & cellulose) but contain anti-nutrients such as cyanide [3]. Direct use of such agro wastes in animal feeds are limited due to low protein content, high fibre or starch content and anti-nutritional factors [4].

The solid-state fermentation (SSF), a promising bioprocess to convert these wastes into more nutritious feed ingredients, has gained attraction [5]. In SSF, a solid substrate (fungi, yeasts, or bacteria) is moisture, so that there is little free water, which allows the metabolism of complex plant polymers into more digestible molecules [6]. SSF can degrade the fibrous matter of agro wastes and enrich it with microbial biomass, therefore detoxifying toxic compounds. This tackles both feed- and environmental-related issues: it supplies alternative feed sources that can partly untether from expensive conventional feeds (e.g. soybean meal or fishmeal) and minimizes pollution from agro-waste disposal by repurposing them in a circular bioeconomy [7]. Many studies on SSF have been conducted in Southeast Asia in recent times, especially within the last ten years, targeting local agro wastes as feed for wide range of animals (poultry, ruminants, fish, and shrimp) [8]. This systematic review summarizes recent information about the utilization of sago hampas, rice bran, palm kernel cake, cassava peels and other similar wastes using SSF in animal nutrition.

II. METHODOLOGY

2.1 Research Design:

This study utilized a systematic literature review (SLR) technique that followed PRISMA criteria to identify and analyze relevant studies from approximately the last ten years (2015–2025) focusing on solid-state fermentation of agro-wastes for animal feed in Southeast Asia [9].

2.2 Search strategy:

A comprehensive search strategy was created in collaboration with a medical librarian to identify relevant studies from electronic databases such as PubMed, Scopus, Web of Science, IEEE Xplore, and the Cochrane Library [10]. The search phrases included keywords such as “solid-state fermentation”, “agro-industrial waste”, “animal feed”, combined with specific terms like “*sago hampas*”, “rice bran”, “palm kernel cake”, and “cassava peel”. The entire search method for each database was described and provided in the supplemental materials. The search was limited to articles published in English between 2015 and 2025, to ensure the inclusion of the most recent and relevant studies.

2.3 Inclusion and Exclusion Criteria:

Inclusion criteria were studies that involved SSF processing of these substrates with the aim of improving their feed value, and which evaluated either the fermentation process (microbial/enzymatic changes) or the feeding outcomes in animals (nutrition or performance). Both experimental research articles and relevant review papers from the last decade were included to ensure coverage of up-to-date findings. Preference was given to studies conducted in or relevant to Southeast Asian conditions, although insightful research from other tropical regions was also considered when applicable.

Studies were included in this review if they investigated SSF as a processing method for agro wastes intended for animal feed and provided detailed information on fermentation parameters, including microbial strains, substrate modifications, and changes in nutritional composition. Additionally, only studies that evaluated the impact of fermented agro wastes on animal performance, digestibility, or feed efficiency were considered. To ensure the inclusion of high-quality and up-to-date research, only studies published in peer-reviewed journals or credible scientific sources between 2015 and 2025 were selected. The geographical focus was on research conducted within Southeast Asia or in tropical regions with comparable agro-climatic conditions. Studies that exclusively examined submerged fermentation (SmF), lacked experimental data, or did not provide sufficient methodological details were excluded from this review.

A systematic approach was employed to extract key data from the selected studies, ensuring consistency and relevance to the research objectives. The extracted information included details on microbial inoculants used in fermentation, such as *Aspergillus spp*., *Trichoderma spp*., *Bacillus spp*., and lactic acid bacteria, as well as fermentation conditions, including duration, temperature, moisture content, and the presence of additives [11,12]. Changes in the chemical composition of agro-wastes post-fermentation were recorded, focusing on crude protein enhancement, fibre reduction, and detoxification of anti-nutrients. Additionally, animal performance indicators such as feed intake, weight gain, digestibility, and overall health parameters were documented. The experimental design and methodological approaches used in each study were also analysed to understand variations in experimental setups and their impact on the findings.

2.4 Data Synthesis and Analysis:

The findings from the included studies were synthesized through a thematic analysis approach, allowing for an organized evaluation of SSF applications. Studies were categorized based on the type of agro waste fermented, the microorganisms utilized, and the observed effects on feed composition and animal performance. A comparative analysis was conducted to identify emerging patterns and trends in SSF application across different substrates and animal species. Furthermore, variations in fermentation efficiency, microbial effectiveness, and feed conversion outcomes were examined to draw broader insights into the potential of SSF as a bioprocessing technique for animal nutrition.

2.5 Quality Assessment:

To ensure the reliability and validity of the included studies, a rigorous quality assessment was performed. Factors such as experimental design quality, sample size, and methodological rigor were critically evaluated [13]. Preference was given to studies with well-defined fermentation protocols and controlled animal feeding trials to ensure that the reported outcomes were robust and replicable. Additionally, any potential biases or inconsistencies in data reporting were noted, allowing for a balanced and objective interpretation of the results.

III. RESULTS

3.1 Study Selection:

The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flow diagram presented in Figure 1 illustrates the systematic process undertaken to identify, screen, and include studies for the review. The process began with the identification phase, where a total of 1,185 records were retrieved from various academic databases. Prior to screening, 821 records were removed, comprising 534 duplicate records and 287 records that were excluded for other reasons, such as irrelevance to the research topic or incomplete data.

Following the removal of these records, 364 studies proceeded to the screening phase, during which their titles and abstracts were reviewed for relevance. At this stage, 216 records were excluded as they did not meet the inclusion criteria. Subsequently, 148 full-text reports were sought for retrieval to facilitate a more detailed assessment. However, 97 of these reports could not be retrieved, likely due to access restrictions or unavailability of full-text versions.

In the eligibility assessment phase, 51 full-text reports were evaluated against the predefined inclusion criteria. During this assessment, 18 reports were excluded because they originated from countries that were not within the geographical scope of the study. Consequently, only 33 studies met the eligibility requirements and were included in the final review. Among these, 24 reports were considered as primary sources for data extraction and synthesis.

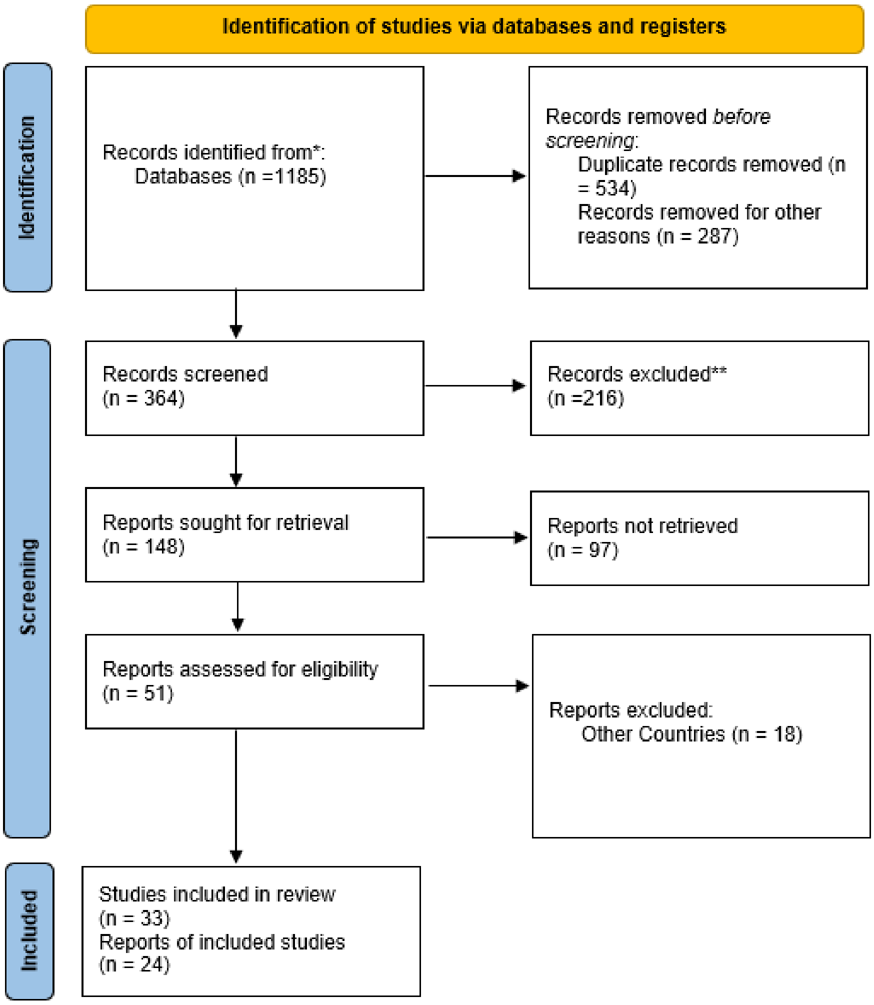


FIGURE 1: PRISMA Flow Diagram (n= number)

3.2 Microbial Strains and Fermentation Conditions:

Various strains of microbes have been used in SSF of agro-wastes, broadly categorized as filamentous fungi, yeast, and bacteria (mostly Bacilli and lactic acid bacteria) [14,15]. Fungal strains are ubiquitous; they produce robust quantities of extracellular enzymes on solid substrates. Aspergillus spp. (e.g., *A. niger*, *A. oryzae*) and *Trichoderma* spp. (e.g. *T. longibrachiatum, T. pseudokoningii*) are commonly utilized because they degrade fibrous ingredients, and protein is enriched in their mycelial [8]. The protein content of palm kernel cake was significantly enhanced (~18.8 – 32.8% CP) and cellulose was reduced from 28% to 12% through fermentation with *Trichoderma longibrachiatum* [16]. Likewise, SSF of PKC with *Aspergillus oryzae* is reported to reduce hemicellulose content by nearly 50% [17].

Edible fungi such as *Pleurotus* (oyster mushroom) have also been evaluated; fermentation of rice bran with *P. sapidus* under SSF conditions (generally ∼25–30 °C for 6–10 days) almost doubled protein from 7.4% to 12.8% [18]. Bacterial inoculants include *Bacillus* spp. (e.g. *B. subtilis, B. amyloliquefaciens, B. licheniformis*), which produce fiber-degrading enzymes, and lactic acid bacteria (e.g., *Lactobacillus plantarum, Weissella confusa*), which ferment carbohydrates and produce organic acids [19]. A study conducted using *Weissella confusa* involved SSF of PKC, coupled with optimized conditions for improving its nutritive value for broilers [20]. Mixed-culture fermentations have also been described (e.g., *B. amyloliquefaciens*, *B. licheniformis, A. niger,* and *A. flavus*), which ferment sago hampas by exploiting the synergetic enzyme activities of bacteria and fungi [15]. Some methods even rely on naturally derived consortia; for example, cassava peels were fermented using a palm wine culture (a natural mixed yeast/bacteria source) to produce a protein-rich ingredient for fish feed [21].

These studies optimize fermentative conditions specific to the microbes chosen and the characteristics of the substrate. Temperature is usually maintained in the mesophilic range (≈25–40°C). Fungi thrive well at around 28–30°C, while some bacterial fermentations (e.g., *Bacillus* spp.) may be carried out at slightly lower temperatures (above 30°C) [17]. Dry fermentations (like *Trichoderma* and *Aspergillus* on agro-wastes) have been achieved at ~28–30°C for 1–3 weeks or at 40°C for 9 days (*Bacillus amyloliquefaciens* with sago hampas) [19]. SSF produces substrates for palatability, and initial protein levels when fermentation (24–48h) is of short duration, whereas longer durations (5–12 days, sometimes even 3 weeks at room temperature) allow substantial fiber degradation and high biomass accumulation [14]. *T. pseudokoningii* needed 12 days of SSF on cassava residue to achieve a substantial protein level, while a mixed probiotic inoculum on sago hampas showed a continuous decrease in fiber content over 7 days but had progressively decreasing returns at 21 days [8].

For SSF, moisture content is an important parameter; it should be sufficiently high to allow for microbial growth but without excess water [18]. Most studies keep 60–75% moisture in the substrate. For optimal microbial activity, sago waste was fermented with a substrate moisture content of approximately 75% w/w (with mineral solution added in a small quantity). Cassava peel fermentations also did well at 60–70% initial moisture [16]. This is usually done by moistening and either sterilizing or pasteurizing substrates before inoculating them with the culture. Another common method is nutrient supplementation: many agro-wastes are often carbon-rich but protein-deficient in nature, so adding a nitrogen source such as urea or ammonium sulphate greatly enhances microbial protein synthesis [21]. One study reported that adding 1% urea to cassava residues in SSF increased protein by 48% (8.4% to 12.5% CP), as fungi had more nitrogen available to incorporate into their biomass [15]. However, some fermentations also require extra mineral salts or co-substrates (i.e., bran or molasses) to facilitate microbial growth [20]. Fermentation is generally done using trays, flasks, or bioreactors, under aerobic conditions (for fungi and *Bacillus*) or in anaerobic/semi-anaerobic conditions for lactic acid bacteria [19]. The process is monitored for temperature (as heat buildup can be an issue in large-scale SSF due to poor heat dissipation), and endpoints are determined by either maximal enzyme activity or nutrient improvement [15]. In general, successful SSF of agro wastes demands careful control of these conditions to stimulate the proliferation of beneficial microbes and degradation of fibrous matter without spoilage.

3.3 Nutritional Improvements in Fermented Agro-Wastes:

Across diverse substrates, SSF has consistently been shown to enhance the nutritional profile of agro wastes [22]. A primary outcome is protein enrichment. As microbes grow on the waste, they assimilate carbon (e.g., fiber, starch) and minerals and incorporate nitrogen (either from the substrate or supplemented) into microbial protein, thereby raising the overall crude protein content of the feed [23]. For example, fermentation of palm kernel cake (PKC) by various microbes often yields a substantial protein boost [24]. Trichoderma-fermented PKC increased crude protein (CP) from approximately 18% to 33% [25]. Similarly, *Aspergillus niger*-fermented PKC has demonstrated improved protein quality and amino acid profiles [26]. Research has also shown that SSF converts rice bran into a higher-protein product, with one study reporting an increase from 7.4% to 12.8% CP using *Pleurotus sapidus* [19]. Furthermore, SSF has been utilized in aquaculture feed formulation, where it was observed to increase protein content, reduce fiber, enhance the amino acid profile, and improve digestibility. Fermented rice bran (FRB) has been recognized as a high-protein feed ingredient capable of partially replacing soybean meal in shrimp diets without compromising growth [16].

In the case of cassava by-products, which typically have very low protein content, SSF can raise protein levels significantly [27]. Fermenting cassava flour or pulp with Aspergillus strains has been shown to increase protein content from approximately 1–4% to over 10% through the production of single-cell protein, representing a 200–300% relative improvement [28]. For cassava peels, *Trichoderma pseudokoningii* SSF resulted in a protein increase of about 48%, from 8.4% to 12.5% CP, under optimal conditions [29]. Though fermented cassava retains a moderate protein level (~12% CP), this still represents a substantial upgrade over the nutritional value of the unfermented peel. Sago hampas, which has an initially low protein content (often 1–4% CP), cannot reach high absolute protein levels through SSF alone unless additional nitrogen is supplied. However, SSF of sago waste has been shown to approximately double its protein content on a percentage basis. For instance, the use of *Aspergillus niger* with 5% urea increased sago hampas' crude protein by about 15% [15].

In addition to protein gains, fiber reduction is a crucial benefit of SSF. Filamentous fungi and some bacteria produce cellulases, xylanases, mannanases, and other fiber-degrading enzymes that break down complex carbohydrates into simpler forms. Studies consistently report decreased crude fiber or structural polysaccharides in fermented products. In fermented PKC, fiber fractions decrease substantially; *Trichoderma longibrachiatum* not only boosted protein content but also reduced cellulose levels from 28.3% to 12.1% [30]. Other work on PKC fermentation with *Paenibacillus* bacteria and fungi found significant reductions in fiber content and concurrent improvements in metabolizable energy [31]. Fermented sago hampas shows a consistent decline in crude fiber content, regardless of the inoculum used. One study observed that mixing sago hampas with rumen liquor and fermenting with *Bacillus amyloliquefaciens* (2% inoculum) for 9 days at 40°C led to a one-third reduction in crude fiber. Another study using a multi-microbe probiotic mix (plus 30% urea) over 21 days achieved approximately a 15% reduction in fiber [32]. In cassava peels, fermentation helps to break down fibrous cell wall components and reduces certain anti-nutrients bound to fiber, improving mineral availability. As fiber is degraded, the fraction of easily digestible components (such as soluble carbohydrates and microbial biomass) increases, enhancing feed energy value and digestibility. In fermented rice bran, for example, total carbohydrate content increased from 36.6% to 50.2% due to fibre breakdown [14].

Another key improvement associated with SSF is increased digestibility and bioavailability of nutrients. By breaking down fibre and anti-nutritional factors, SSF makes more nutrients accessible to animals. In ruminants, whose microbiomes can ferment fibre, SSF-treated agro-waste has been linked to higher feed intake and improved dry matter digestibility. For example, including up to 50% fermented sago hampas in a ruminant diet resulted in approximately 68% digestibility—significantly higher than diets with unfermented hampas [33]. In non-ruminants, including poultry, fish, and pigs, fibre removal and carbohydrate breakdown are particularly beneficial. Poultry studies have noted improved energy metabolizable and amino acid digestibility when PKC or rice bran undergo SSF. For instance, broilers fed diets containing fermented PKC exhibited better nutrient digestibility than those consuming raw PKC diets [15]. In aquaculture, apparent digestibility coefficients for protein increased when fermented ingredients replaced raw agro-wastes in feed formulations [19].

The SSF process also aids in the degradation of specific anti-nutrients. Fermentation tends to reduce phytic acid levels in fibrous residues, as seen with cassava peels, where phytate phosphorus content dropped from approximately 1% to 0.7% (Abu Yazid et al., 2017). Similarly, rice bran, which is rich in phytate, undergoes partial phytate hydrolysis by microbial phytases during SSF. In cassava, cyanogenic glycosides (which release toxic hydrogen cyanide) are significantly reduced through fermentation and drying, as these processes facilitate cyanide evaporation and microbial enzymatic degradation of linamarin. Consequently, fermented cassava products are safer for animal consumption than raw peels, which pose a risk of cyanide poisoning [32].

Additionally, SSF can enhance beneficial compounds. Some fermentations increase vitamin levels (e.g., B-vitamins produced by yeasts or bacteria) or introduce enzymes and metabolites that act as digestive aids or probiotics. Fermented feeds often contain lactic acid and other organic acids, which lower pH and improve gut health. There is evidence that fermented liquid feeds can reduce pathogenic bacterial loads in poultry. For example, one study found that feeding fermented diets reduced broiler susceptibility to Salmonella infections [14]. While the primary focus of SSF research is on nutritional enhancements, these health benefits represent valuable secondary advantages.

3.4 Comparative Analysis of Different Substrates:

Due to their different compositions, different agro-waste substrates respond to SSF in different ways. A summary comparation of 4 major substrates (sago hampas, rice bran, palm kernel cake, cassava peels). Sago Hampas are high in fiber (lignocellulose) and also has residual starch, it has very low native protein (1–3% CP) and high crude fiber (generally >30%) because of its low protein, unmodified sago hampas is still lacking in protein compared to more common feeds, and this is also true for fermented sago hampas unless external nitrogen is introduced [34]. Reducing fiber content and improving digestibility is the main advantage of using SSF on sago. Multi-strain fermentation considerably reduces fibre content (by up to 33% reduction on total fibre) [35]. Sago hampas also contains a high amount of non-fibrus carbohydrate (NFE) (starch), which is a good energy source for ruminants, but at the same time, the starch can support microbial growth during SSF [25]. According to comparative studies, fermented sago hampas can replace some of the commonly used energy feed, as long as it is supplemented with protein sources (as in the case of ruminants, urea). Fermented sago waste showed potential in aquaculture and ruminant systems in feed trials. And in a test on fish diets, inclusion of 15% fermented sago waste (150 g/kg) in a tilapia feed produced statistically equivalent growth rates to a control diet containing fishmeal [36]. This shows that fermented sago hampas is an efficient supplier of energy and nutritional sources including vitamins, even at very low protein levels, making it an appropriate practical step when properly balanced. Sago hampas can be a source of basal roughage for ruminants and it has been concluded in one review that fermented sago hampas in cattle feed (up to around 50% of diet dry matter) would still allow reasonable growth and digestibility, although raw hampas in high proportions would grossly limit performance [37].

Rice bran (10–15% CP) is moderately nutrient-dense, when it comes to a high fat (15–20% ether extract) and 8–12% fiber it plus starch residues [38]. The major concerns are rancidity (from lipase activity in the oil) and phytate and other inhibitors that can lower the bioavailability of minerals and proteins [39]. SSF acts to stabilize the rice bran by eliminating or reducing lipid content and serve to enhance protein and digestibility in rice bran. Lipid content decreased (possibly from 48.5 to 27.8 % of DM) in the case of rice bran in SSF with Pleurotus indicating oil utilization as an energy source by the organism, preventing rancidity and increasing other nutrients. In parallel, dietary protein was increased to 13% [40]. Fermentation improves the amino acid balance of rice bran: feeding it to microbes increases the protein content, and the microorganisms produce high-quality protein that can be used to supplement the low-lysine protein found in rice [41]. Compared to other commonly used feed ingredients, fermented rice bran is relatively well-balanced, with moderate protein (lower than fermented PKC, but more than fermented cassava or fermented sago), moderate fiber, and a bit of residual oil for energy [42]. It has been extensively tested for use in monogastrics and aquaculture. For instance, fermented rice bran completely replaced soybean meal at 25–50% in shrimp (Penaeus monodon) feeding trials and had no adverse effect on either growth performance or carcass composition [43].

At 25% replacement, shrimp growth even improved, likely due to enhanced palatability or micronutrients from the fermentation. This indicates fermented rice bran can partially substitute expensive protein sources [44]. In poultry and pig diets, fermented rice bran is often included at 5–15% as an energy-protein source with positive results on feed efficiency compared to raw bran [45]. Thus, relative to other wastes, rice bran under SSF becomes a high-quality feed ingredient with a balance of protein and energy, suitable for all animal categories (and especially valuable in non-ruminant diets where raw bran's utility is limited by anti-nutrients).

Palm Kernel Cake (PKC) is a fibrous residue which is high in protein (14–18%) and fiber (up to 20% CF) with mannan-rich polysaccharide. PKC is among the substrates for which SSF provides some of the largest gains [46]. Fermentation can elevate its CP to oilseed meal level, to begin with, being richer in protein. All fungal treatments (e.g. Aspergillus, Trichoderma) significantly increased PKC protein to the 25–30% range so "fermented PKC" could be used as a local replacement for soybean meal, a common ingredient in poultry diets [47]. The fiber (mostly mannans and cellulose) is highly degraded, a key factor because raw PKC's high fiber content makes it less suited for use in non-ruminants. In one comparative study, the hemicellulose content of Aspergillus oryzae-fermented PKC was found to be markedly lower compared to the corresponding unfermented PKC (~19% vs 37% originally) [48]. Additionally, fermentation is a unique opportunity for PKC, to develop value-added end-products, *Paenibacillus,* and other inoculants, can be utilized to convert fibre from PKC to mannan-oligosaccharides (MOS), which although used as a prebiotic in animal feedings have their own benefits [49]. When compared across wastes fermented PKC is particularly advantageous to poultry and pigs as it changes PKC from a primarily ruminant feed (in raw form) to a more universally digested feed [50]. When PKC is fermented and incorporated at levels of 10–20% of a broiler's diet, the quality of performance based upon weight gain and feed conversion is remarkably improved compared to that of raw PKC included at levels which would suppress performance if fed. Reduced fiber and beneficial fermentation metabolites in fermented PKC contributed to enhanced growth and gut health of broilers in heat-stressed tropical climates. Fermented PKC has higher protein and bypass nutrients that could benefit ruminants, which can also utilize raw PKC. More specifically, studies conducted in dairy cattle showed an increase in milk yield and quality when some of the concentrate was exchanged for fermented PKC (due to increased undegradable protein and nutrient density) [51]. Hence PKC through SSF becomes a high digestibility, protein-rich feed when you compare it. It also has a higher baseline content of the nutrient in question, so unless it's otherwise counter-intuitive, it will typically produce the most nutritious product, it had the highest absolute protein.

Cassava Peels (and Pulp) remains are basically energy-dense, protein-poor substrates. Peels contain 5% of CP and more than 50–60% of carbohydrates (mostly starch and fiber) [52]. They also have anti-nutritional cyanogenic glycosides that should be reduced. SSF provides moderate protein enrichment, often elevating CP into the 10–15% range upon N, supplementations and acts to detoxify the cassava waste; Though fermented cassava peels have lower protein compared to fermented PKC or rice bran, this feed has the advantage of being a safe and appetizing energy source that can become a partial substitute for the inclusion of grains [53]. For instance, fungi- or rumen-microbe-based fermentation of cassava peels improves their nutrition with lots of microbial protein and reduces the content of cyanide to safe levels (far below 50 mg/kg) [54]. This means cassava peel–based feeds could be used much more widely. A fermented cassava peel product (sometimes referred to as cassava peel silage or SCOB – single cell protein biomass) has been tested and successfully replaced maize or other energy sources in feeding trials in swine and poultry in proportions of ca. 20–30% inclusion, usually with positive or no negative effect on growth [55]. In one study in broilers, a mixture of fermented cassava pulp and PKC fully replaced maize without a drop in weight gain, as long as amino acids were balanced [56]. Use of dried fermented cassava peels (sometimes fermented with yeast from palm wine or with rumen fluid) as a protein/carbohydrate source in fish has also been investigated [57]. In tilapia fishes feed, this type of diet outperformed raw cassava peel and even fishmeal alone and displayed slightly lower performance than a soybean meal diet. Implying that fermented cassava can serve as a source of energy and a fair amount of protein [58]. Cassava wastes may need more attention than others to become detoxified, as SSF represents a biological detox method (especially with select bacteria). They generally require nitrogen supplements (e.g., urea, soybean waste, etc.) to ensure that fermentation produces a viable protein feed. However, the transformation of cassava peels into feed would have a considerable impact due to the large number of cassavas in Southeast Asia (Thailand, Indonesia, etc.) and Africa. Economically, it makes what is fundamentally a disposal problem a feed resource [59]. Overall, fermented cassava peels are a decent energy feed and, with some protein supplementation, are better than raw peels, but nutritionally they are a step down from fermented PKC or rice bran as they have less protein.

Higher initial protein substrates (such as PKC, rice bran) generally produce fermented products that can be used as protein concentrates. Those that are very low in protein (i.e., sago, cassava) are essentially enhanced energy sources but with some additional protein and highly- fibrous substrates (PKC, sago) experience the most skilled reduction of fiber in terms of the fiber, which better locates its usage into a non-ruminant animal [60]. Substrates with a high starch content (cassava, sago etc.) readily support mycelium growth and can, therefore, grow microbial protein if nitrogen is not limiting. Each substrate can be metabolized by different microbes: *Neurospora crassa* has been traditionally used in Indonesia as a means of fermenting cassava waste into high-protein biomass ("oncom" feed), while things like white-rot fungi such as *Pleurotus* can flourish on high-fat rice bran because they can metabolize lipids [61]. These differences highlight the need to optimize SSF conditions for each individual waste. However, all these agro wastes can be bioconverted using SSF to become more nutrient-rich, using less conventional feed ingredients in the poultry, ruminants, and aquaculture species that previously could not properly use the raw forms. In practice, the choice of fermented substrate may be determined by local availability and the animals targeted, a farmer in Malaysia, for example, might use fermented PKC for chickens (taking advantage of the country's abundant palm oil wastes), while an Indonesian farmer might use fermented cassava peels and sago hampas for cattle in an area where those substrates are available in abundance.

IV. DISCUSSION

The above results demonstrate that solid-state fermentation is a powerful tool for valorising agro waste into animal feed, but realizing its full potential involves understanding its benefits and challenges in practical contexts, as well as its broader impact on sustainability and economics. The benefits of solid-state fermentation (SSF) for animal feed production are numerous, beginning with nutrient enhancement. SSF significantly improves the nutritional profile of agro-waste-derived feed by increasing protein content and enhancing fiber digestibility, which directly contributes to better animal growth performance and overall health [62]. Fermented palm kernel cake (PKC) and rice bran can partially replace imported soybean meal in livestock diets, while fermented sago and cassava can serve as substitutes for a portion of cereal grains, thus diversifying protein and energy sources. Additionally, microbial fermentation enriches the feed with B-vitamins, enzymes, and amino acids, improving its overall nutritional balance. Studies have shown that livestock and fish fed fermented feed exhibit equal or superior weight gains and feed conversion ratios compared to those on unfermented counterparts, further validating the benefits of SSF in vivo [63,64].

Another significant advantage of SSF is its ability to utilize locally abundant, low-cost resources. Southeast Asia produces large quantities of agro-industrial by-products such as PKC in Malaysia and Indonesia and rice bran in rice-producing countries. By transforming these materials into animal feed, SSF reduces reliance on costly imported feed ingredients such as soybean meal and corn [1,46]. This process not only lowers production costs for farmers but also enhances feed security by leveraging readily available agricultural residues. Fermented agro-waste feeds are often cheaper per unit of nutrient compared to conventional commercial feeds, making them an economically viable solution for sustainable livestock production [65].

Beyond economic benefits, SSF promotes environmental sustainability by mitigating waste disposal challenges. Large-scale agricultural operations generate significant amounts of by-products that, if left unused, can contribute to environmental pollution [66]. For example, PKC and sago hampas in Malaysia and Indonesia pose major waste management challenges, but SSF enables their reintegration into the farm production cycle. By converting these residues into nutritious feed, SSF reduces open dumping and burning, which can cause environmental hazards such as methane emissions and soil degradation. Furthermore, by replacing a portion of conventional feed ingredients, SSF reduces the need for additional cropland for feed cultivation or wild fish harvesting for fishmeal, thereby alleviating land use pressure and contributing to more sustainable food systems [67].

Animal health and feed safety also benefit from SSF, as fermentation can improve gut health and inhibit pathogens. Organic acids such as lactic and acetic acids lower feed pH, creating an unfavorable environment for harmful bacteria, including *Salmonella* and *E. coli*. Studies indicate that fermented feed in poultry and swine diets can significantly reduce the incidence of these pathogens while promoting beneficial gut microbiota [68,69,70]. Additionally, some fermented feed products act as natural probiotics or prebiotics, as seen with mannan-oligosaccharides (MOS) derived from fermented PKC, which support gut health and immune function. Fermentation can also detoxify harmful compounds, breaking down mycotoxins, cyanogenic glycosides, and other anti-nutritional factors, thereby improving overall feed safety. These effects contribute to healthier animals, potentially reducing the need for antibiotics and chemical additives in livestock diets.

Moreover, SSF-derived feeds demonstrate remarkable adaptability across various animal production systems. Ruminants benefit from increased rumen-degradable protein and improved fiber digestibility in fermented roughages, allowing for better nutrient absorption and growth performance. Non-ruminants, such as poultry and pigs, benefit from reduced fiber and anti-nutritional content in fermented feeds, enabling higher inclusion rates of agro-waste-derived ingredients without compromising performance. In aquaculture, fermented plant-based ingredients are more readily accepted by fish and shrimp due to improved palatability and reduced off-flavors. For instance, the fermentation of rice bran has been shown to enhance its "umami" amino acid content, potentially improving shrimp feed acceptability and growth outcomes. The versatility of SSF feeds makes them well-suited for integrated farming systems, where a single waste stream can be processed and utilized across multiple animal species [71]. A farm practicing SSF, for example, could ferment agro-waste and use the resulting feed for both cattle and fish in a polyculture setup, maximizing resource efficiency and minimizing wastePreparation of inoculum and substrates are another critical challenge in SSF. While a reliable inoculum is important, it may pose a challenge, particularly to smallholders. Some fermentations use naturally occurring microbes, as with rumen fluid or palm wine starters, but pure or well-defined mixed cultures (e.g., specific *Aspergillus* or *Bacillus* species) are often needed to achieve reproducible results. These starter cultures might have to be prepared in a lab, which necessarily is less accessible. Moreover, a number of substrates need to be pretreated to achieve optimal fermentation efficiency. This includes drying, grinding to create surface area, altering pH or adding nutritional additives, all of which add labor and cost. Cassava peels, for instance, usually need being chopped and soaked prior to being fermented in order to drop cyanide ranges. For small-scale farmers, however, these preparatory steps can be cumbersome without adequate training or equipment.

V. CONCLUSION

Solid-state fermentation has emerged as a viable strategy to transform Southeast Asia's abundant organic residues into premium livestock feed ingredients. Throughout the past decade, widespread investigation has demonstrated that prevalent local wastes – like sago filter cakes, rice bran, palm kernel cake, and cassava peels – can be biologically processed with molds and microbes to significantly better their nutritional worth. This thorough review highlighted that SSF generally heightens crude protein (through microbial biomass formation) and reduces fibrous portions, thereby enhancing the digestibility and feed value of these materials. A variety of microbial strains (for example, Aspergillus, Trichoderma, Bacillus, Lactobacillus) have effectively been utilized, under conditions of fermentation usually surrounding 28–37°C, 60–75% moisture, and 5–14 days duration, regularly with nutrient supplementation to optimize growth. The fermented products have displayed promising outcomes across animal types: poultry diets with fermented PKC or cassava have boosted development and feed proficiency, ruminants have superior digestibility and performance on diets containing fermented sago or rice bran, and fish/shrimp feeds incorporating fermented rice bran or cassava peels can partly change traditional ingredients without loss of productivity.

Comparative analysis sheds light on how varied agro-waste responses can be – for instance, palm kernel cake experiences major boosts to protein content and digestibility, allowing its use as a protein-packed feed for non-ruminants. Meanwhile, cassava peels become safely used for energy once cyanide levels reduce, though they enrich less dramatically. These insights permit targeted applications: utilizing fermented rice bran or palm kernel cake to replace costly concentrates, and high-fiber fermented refuse like *sago hampas* fulfilling roughage and energy roles in ruminant rations. Embracing SSF for feed brings manifold advantages – it fosters waste reuse and environmental sustainability, lessens feed expenses and reliance on imports, and may enhance animal gut wellness through probiotic effects. However, maintaining fermentation quality, confirming economic feasibility, and scaling the process beyond labs to farms remain challenges. Addressing such hurdles will prove pivotal to broader industry adoption. Developing starter culture kits, modular fermenters like bags or silos, plus merging SSF into prevailing agro-industrial operations can smooth practical implementation.

In conclusion, solid-state fermentation offers a compelling pathway to enhance feed security and sustainability in Southeast Asia. By transforming diverse agro-wastes into nutritious feed, it recycles environmental burdens into economic gains – aligning precisely with aims of circular agriculture and zero-waste goals. Experiments over the past decade prove conclusively that animals can thrive on diets incorporating sizable portions of fermented by-products. Moving forward, efforts must optimize fermentation techniques, conduct extensive on-farm tests to calibrate suitable inclusion levels for various species, and carry out cost-benefit analyses in real settings. With persistent innovation and assistance, SSF of agro wastes is well-positioned to shift from exploration studies into standard agricultural practice, contributing importantly to a more resilient and sustainable animal agriculture sector in Southeast Asia and beyond. Evidence compiled herein serves as a knowledge base to propel this transition, confirming that residual materials from one process indeed represent “treasure” as healthy animal nourishment.

ACKNOWLEDGEMENTS

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

REFERENCES

[1] Wan-Mohtar, W. A. A. Q. I., Khalid, N. I., Rahim, M. H. A., Luthfi, A. A. I., Zaini, N. S. M., Din, N. A. S., & Mohd Zaini, N. A. (2023). Underutilized Malaysian agro-industrial wastes as sustainable carbon sources for lactic acid production. Fermentation, 9(10), 905.

[2] Mirnawati, M., Ciptaan, G., & Ferawati, F. (2019). Improving the quality and nutrient content of palm kernel cake through fermentation with Bacillus subtilis.

[3] Zubair, J. B. (2024). Effect of Lactic Acid Bacteria Treated Gliricidia-Cassava Peels Mixtures Silage on Performance Characteristics and Blood Profile of West Africa Dwarf (WAD) Goats (Master's thesis, Kwara State University (Nigeria)).

[4] Kundmann, A. C., Flynn, A., Wood, D. F., Orts, W. J., & Hart-Cooper, W. (2024). Animal feed production and analysis from egg and almond hull agricultural waste. Journal of Applied Animal Research, 52(1), 2426984.

[5] Bamidele, M. O., Bamikale, M. B., Cárdenas-Hernández, E., Bamidele, M. A., Castillo-Olvera, G., Sandoval-Cortes, J., & Aguilar, C. N. (2025). Bioengineering in solid-state fermentation for next sustainable food bioprocessing. Next Sustainability, 6, 100105.

[6] Postigo, L. O. C., Jacobo-Velázquez, D. A., Guajardo-Flores, D., Amezquita, L. E. G., & García-Cayuela, T. (2021). Solid-state fermentation for enhancing the nutraceutical content of agrifood by-products: Recent advances and its industrial feasibility. Food Bioscience, 41, 100926.

[7] Perwez, M., & Al Asheh, S. (2024). Valorization of agro-industrial waste through solid-state fermentation: Mini review. Biotechnology reports (Amsterdam, Netherlands), 45, e00873. https://doi.org/10.1016/j.btre.2024.e00873

[8] Yafetto, L., Odamtten, G. T., & Wiafe-Kwagyan, M. (2023). Valorization of agro-industrial wastes into animal feed through microbial fermentation: A review of the global and Ghanaian case. Heliyon, 9(4).

[9] Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., ... & Moher, D. (2021). The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. bmj, 372.

[10] Gusenbauer, M., & Haddaway, N. R. (2020). Which academic search systems are suitable for systematic reviews or meta-analyses? Evaluating retrieval qualities of Google Scholar, PubMed, and 26 other resources. Research synthesis methods, 11(2), 181-217.

[11] Díaz-Rodríguez, A. M., Parra Cota, F. I., Cira Chávez, L. A., García Ortega, L. F., Estrada Alvarado, M. I., Santoyo, G., & de Los Santos-Villalobos, S. (2025). Microbial Inoculants in Sustainable Agriculture: Advancements, Challenges, and Future Directions. Plants, 14(2), 191.

[12] Dong, M., Li, Q., Xu, F., Wang, S., Chen, J., & Li, W. (2020). Effects of microbial inoculants on the fermentation characteristics and microbial communities of sweet sorghum bagasse silage. Scientific Reports, 10(1), 837.

[13] Shaheen, N., Shaheen, A., Ramadan, A., Hefnawy, M. T., Ramadan, A., Ibrahim, I. A., Hassanein, M. E., Ashour, M. E., & Flouty, O. (2023). Appraising systematic reviews: a comprehensive guide to ensuring validity and reliability. Frontiers in research metrics and analytics, 8, 1268045. https://doi.org/10.3389/frma.2023.1268045

[14] Sadh, P. K., Duhan, S., & Duhan, J. S. (2018). Agro-industrial wastes and their utilization using solid-state fermentation: a review.

[15] Bibi, F., Ilyas, N., Saeed, M., Shabir, S., & Shati, A. A. (2023). Innovative production of value-added products using agro-industrial wastes via solid-state fermentation.

[16] Selo, G., Planinić, M., Tišma, M., & Tomas, S. (2021). A comprehensive review on valorization of agro-food industrial residues by solid-state fermentation.

[17] Ametefe, G. D., Lemo, A. O., Orji, F. A., & Lawal, A. K. (2022). Pectinase activities of selected fungi grown on agrowastes via solid-state fermentation.

[18] Alpers, T., Kerpes, R., Frioli, M., Nobis, A., Hoi, K. I., Bach, A., ... & Becker, T. (2021). Impact of storing condition on staling and microbial spoilage behavior of bread and their contribution to prevent food waste. Foods, 10(1), 76.

[19] Kumar, V., Naik, B., Choudhary, M., & Kumar, A. (2022). Agro-waste as a substrate for the production of pullulanase by Penicillium viridicatum under solid-state fermentation.

[20] Mahmoud, E., Ramadan, M., & Ismail, M. M. (2022). Production of flavors from agro waste of Ocimum basilicum L. by different microorganisms using solid-state fermentation. Egyptian Journal of Chemistry.

[21] Naik, B., Goyal, S. K., Tripathi, A. D., & Kumar, V. (2019). Screening of agro-industrial waste and physical factors for the optimum production of pullulanase in solid-state fermentation from endophytic Aspergillus sp.

[22] Bajić, B., Vučurović, D., Vasić, Đ., Jevtić-Mučibabić, R., & Dodić, S. (2022). Biotechnological production of sustainable microbial proteins from agro-industrial residues and by-products. Foods, 12(1), 107.

[23] Rasool, K., Hussain, S., Shahzad, A., Miran, W., Mahmoud, K. A., Ali, N., & Almomani, F. (2023). Comprehensive insights into sustainable conversion of agricultural and food waste into microbial protein for animal feed production. Reviews in Environmental Science and Bio/Technology, 22(2), 527-562.

[24] Zeng, H., Miao, J., Liao, J., Sui, Z., Hou, M., & Hang, S. (2024). Palm Kernel Cake Extracts Obtained from the Combination of Bacterial Fermentation and Enzymic Hydrolysis Promote Swine Small Intestine IPEC-J2 Cell Proliferation and Alleviate LPS-Induced Inflammation In Vitro. Antioxidants, 13(6), 682.

[25] Wardono, H. P., Agus, A., Astuti, A., Ngadiyono, N., & Suhartanto, B. (2022, February). The effect of fermentation time on the nutritional value of sago hampas. In 9th International Seminar on Tropical Animal Production (ISTAP 2021) (pp. 97-102). Atlantis Press.

[26] Uche, F. O., Eggbune, E. O., Anigboro, A. A., & Tonukari, N. J. (2024). Assessment of Biochemical Potential of Rhizopus oligosporus as Starter Culture to Enhance the Nutritional Value of Palm Kernel Cake for Animal Feed Formulation. Journal of Applied Sciences and Environmental Management, 28(9), 2887-2903.

[27] Vandenberghe, L. P., Pandey, A., Carvalho, J. C., Letti, L. A., Woiciechowski, A. L., Karp, S. G., ... & Soccol, C. R. (2021). Solid-state fermentation technology and innovation for the production of agricultural and animal feed bioproducts. Systems Microbiology and Biomanufacturing, 1, 142-165.

[28] Sathya, R., Varghese, R., & Arasu, M. V. (2023). Vágvölgyi Csaba, Pankaj Kumar, RC Dubey 14 Agro-food industrial residues into enzymes and other products using solid-state fermentation. Microbial Oxidative Enzymes: Biotechnological Applications, 281.

[29] Inga, M., Betalleluz-Pallardel, I., Puma-Isuiza, G., Cumpa-Arias, L., Osorio, C., Valdez-Arana, J. D. C., & Vargas-De-La-Cruz, C. (2024). Chemical analysis and bioactive compounds from agrifood by-products of peruvian crops. Frontiers in Sustainable Food Systems, 8, 1341895.

[30] Yafetto, L. (2022). Application of solid-state fermentation by microbial biotechnology for bioprocessing of agro-industrial wastes from 1970 to 2020: A review and bibliometric analysis.

[31] Abu Yazid, N., Barrena, R., Komilis, D., & Sánchez, A. (2017). Solid-state fermentation as a novel paradigm for organic waste valorization: a review. Sustainability, 9(2), 224.

[32] Murugesan, G., & Shenpagam, D. N. H. (2015) Synthesis And Characterization Of Neutral Protease From Agro Waste By Solid State Fermentation. Pharmanest - An International Journal Of Advances In Pharmaceutical Sciences, 6(6)

[33] Wardono, H. P., Agus, A., Astuti, A., Ngadiyono, N., & Suhartanto, B. (2021). Potential of sago hampas for ruminants feed. In E3S Web of Conferences (Vol. 306, p. 05012). EDP Sciences.

[34] Fetriyuna, F., Letsoin, S. M. A., Jati, I. R. A., & Purwestri, R. C. (2024). Potential of Underutilized Sago for Bioenergy Uses. International Journal on Advanced Science, Engineering & Information Technology, 14(1).

[35] Sandar, S. (2022). Potential of neglected biomass and industrial side-streams utilization in biofuels production.

[36] Lani, N., Husaini, A., Ngieng, N. S., Lee, K. S., RAHIM, K. A. A., Roslan, H. A., & Esa, Y. (2021). Solid substrate fermentation of sago waste and its evaluation as feed ingredient for red hybrid tilapia. Malaysian Applied Biology, 50(1), 85-94.

[37] Tiro, B. M. W., Beding, P. A., & Baliadi, Y. (2018, February). The utilization of sago waste as cattle feed. In IOP Conference Series: Earth and Environmental Science (Vol. 119, No. 1, p. 012038). IOP Publishing.

[38] Sapwarobol, S., Saphyakhajorn, W., & Astina, J. (2021). Biological Functions and Activities of Rice Bran as a Functional Ingredient: A Review. Nutrition and metabolic insights, 14, 11786388211058559. https://doi.org/10.1177/11786388211058559

[39] Sahini, M. G., & Mutegoa, E. (2023). Extraction, phytochemistry, nutritional, and therapeutical potentials of rice bran oil: A review. Phytomedicine Plus, 3(2), 100453.

[40] Omarini, A. B., Labuckas, D., Zunino, M. P., Pizzolitto, R., Fernández-Lahore, M., Barrionuevo, D., & Zygadlo, J. A. (2019). Upgrading the nutritional value of rice bran by solid-state fermentation with Pleurotus sapidus. Fermentation, 5(2), 44.

[41] Seyoum, Y., Humblot, C., Baxter, B. A., Nealon, N. J., Weber, A. M., & Ryan, E. P. (2022). Metabolomics of Rice Bran Differentially Impacted by Fermentation With Six Probiotics Demonstrates Key Nutrient Changes for Enhancing Gut Health. Frontiers in nutrition, 8, 795334. https://doi.org/10.3389/fnut.2021.795334

[42] Manlapig, J. J. D., & Matsui, H. (2025). Production and Utilization of Fermented Rice Bran as Animal Feed. Animal science journal = Nihon chikusan Gakkaiho, 96(1), e70037. https://doi.org/10.1111/asj.70037

[43] Huervana, F. H., Traifalgar, R. F. M., & Dionela, C. S. (2024). Solid-state fermentation converts rice bran into a high-protein feed ingredient for Penaeus monodon. Frontiers in Marine Science, 11, 1384492.

[44] Wang, Y., Zheng, W., Deng, W., Fang, H., Hu, H., Zhu, H., & Yao, W. (2023). Effect of fermented heat-treated rice bran on performance and possible role of intestinal microbiota in laying hens. Frontiers in Microbiology, 14, 1144567.

[45] Haryati, T., Susanti, T., & Susana, I. W. R. (2015). Nutritional value of rice bran fermented by Bacillus amyloliquefaciens and humic substances and its utilization as a feed ingredient for broiler chickens. Asian-Australasian journal of animal sciences, 28(2), 231.

[46] Azizi, M. N., Loh, T. C., Foo, H. L., & Teik Chung, E. L. (2021). Is palm kernel cake a suitable alternative feed ingredient for poultry?. Animals, 11(2), 338.

[47] Abdeltawab, A. M., & Khattab, M. S. (2018). Utilization of palm kernel cake as a ruminant feed for animal: A review. Asian J. Biol. Sci, 11(4), 157-164.

[48] Gomez-Osorio, L. M., Nielsen, J. U., Martens, H. J., & Wimmer, R. (2022). Upgrading the Nutritional Value of PKC Using a Bacillus subtilis Derived Monocomponent β-Mannanase. Molecules (Basel, Switzerland), 27(2), 563.
https://doi.org/10.3390/molecules27020563

[49] Tiwari, U. P., Fleming, S. A., Rasheed, M. S. A., Jha, R., & Dilger, R. N. (2020). The role of oligosaccharides and polysaccharides of xylan and mannan in gut health of monogastric animals. Journal of nutritional science, 9, e21.

[50] Ong, W. L., Chan, K. L., Suwanto, A., Li, Z., Ng, K. H., & Zhou, K. (2024). Hydrolysis of palm kernel meal fibre using a newly isolated Bacillus subtilis F6 with high mannanase activity. Bioresources and bioprocessing, 11(1), 113.
https://doi.org/10.1186/s40643-024-00826-9

[51] Ferreira, F. G., Leite, L. C., Alba, H. D. R., Pina, D. D. S., Santos, S. A., Tosto, M. S. L., Rodrigues, C. S., de Lima Júnior, D. M., de Oliveira, J. S., de Freitas Júnior, J. E., de C Mesquita, B. M. A., & de Carvalho, G. G. P. (2022). Palm Kernel Cake in Diets for Lactating Goats: Intake, Digestibility, Feeding Behavior, Milk Production, and Nitrogen Metabolism. Animals : an open access journal from MDPI, 12(18), 2323. https://doi.org/10.3390/ani12182323

[52] Lomwongsopon, P., & Aramrueang, N. (2022). Mild chemical pretreatment of cassava pulp for enhancing high-load anaerobic digestion. Bioresource Technology Reports, 17, 100896.

[53] Godoy, Mateus & Freire, Denise. (2018). Agricultural Residues as Animal Feed: Protein Enrichment and Detoxification Using Solid-State Fermentation.

[54] Gunun, P., Cherdthong, A., Khejornsart, P., Wanapat, M., Polyorach, S., Kaewwongsa, W., & Gunun, N. (2023). Replacing concentrate with yeast-or EM-Fermented cassava peel (YFCP or EMFCP): Effects on the feed intake, feed digestibility, rumen fermentation, and growth performance of goats. Animals, 13(4), 551.

[55] Heuzé, V., Tran, G., Archimede, H., Regnier, C., Bastianelli, D., & Lebas, F. (2016). Cassava peels, cassava pomace and other cassava by-products.

[56] Chang'a, Edwin & Abdallh, Medani & Ahiwe, Emmanuel & Mbaga, Said & Zhu, Ze & Fru, Fidelis & Iji, Paul. (2019). Replacement value of cassava for maize in broiler chicken diets supplemented with enzymes. Asian-Australasian Journal of Animal Sciences. 33. 10.5713/ajas.19.0263.

[57] Andriani, Yuli & Pratama, Rusky & Harlina, Putri. (2023). POTENTIAL UTILIZATION OF CASSAVA PEEL WASTE FOR FISH FEED. 21-27. 10.5281/zenodo.8137841.

[58] Talukdar, Anik & Rahman, Md & Islam, Md & Alam, Mohammad & Rahman, Flura. (2023). Alternative protein sources as a replacement of fish meal in the diet of Oreochromis niloticus: A review. Archives of Agriculture and Environmental Science. 8. 442-451.

[59] Jumare, Fatimah Ibrahim & Salleh, Madihah & Ihsan, Nurashikin & Hussin, Huszalina. (2024). Cassava waste as an animal feed treatment: past and future. Reviews in Environmental Science and Bio/Technology. 23. 1-30. 10.1007/s11157-024-09701-7.

[60] Djulardi, Ade & Mirnawati, Mirnawati & Ciptaan, Gita & Kurnia, Ridho & Srifani, Anifah & Adriani, Lovita & Makmur, Malik. (2023). Improving the Quality and Nutritional Value of a Mixture of Sago Pith and Indigofera Leaves Fermented with Rhizopus oligosporus. World s Veterinary Journal. 13. 580-586. 10.54203/scil.2023.wvj62.

[61] Karimi, S. (2024). Filamentous Fungi as a Sustainable Ingredient for Fish Feed (Doctoral dissertation, Högskolan i Borås).

[62] Sousa, D., Moset, V., del Carmen López-Luján, M., Salgado, J. M., Dias, A., Belo, I., ... & Cambra-López, M. (2024). Potential of solid-state fermentation to enhance the nutritional value of oilseed cakes for poultry. *Animal Feed Science and Technology*, *316*, 116056.

[63] Jiang, W., Jia, X., Xie, N., Wen, C., Ma, S., Jiang, G., ... & Liu, W. (2023). Aquafeed fermentation improves dietary nutritional quality and benefits feeding behavior, meat flavor, and intestinal microbiota of Chinese mitten crab (Eriocheir sinensis). *Animal Nutrition*, *14*, 1-19.

[64] Lambo, M. T., Ma, H., Zhang, H., Song, P., Mao, H., Cui, G., ... & Zhang, Y. (2024). Mechanism of action, benefits, and research gap in fermented soybean meal utilization as a high-quality protein source for livestock and poultry. *Animal Nutrition*, *16*, 130-146.

[65] Riseh, R. S., Vazvani, M. G., Hassanisaadi, M., & Thakur, V. K. (2024). Agricultural wastes: A practical and potential source for the isolation and preparation of cellulose and application in agriculture and different industries. *Industrial Crops and Products*, *208*, 117904.

[66] Adejumo, I. O., & Adebiyi, O. A. (2020). Agricultural Solid Wastes: Causes, Effects, and Effective Management. Chapter 10. *Saleh, HM, Strategies of Sustainable Solid Waste Management. IntechOpen. doi*, *10*.

[67] Albrektsen, S., Kortet, R., Skov, P. V., Ytteborg, E., Gitlesen, S., Kleinegris, D., ... & Øverland, M. (2022). Future feed resources in sustainable salmonid production: A review. *Reviews in aquaculture*, *14*(4), 1790-1812.

[68] Peng, W., Talpur, M. Z., Zeng, Y., Xie, P., Li, J., Wang, S., ... & Zhang, H. (2022). Influence of fermented feed additive on gut morphology, immune status, and microbiota in broilers. *BMC Veterinary Research*, *18*(1), 218.

[69] 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.

[70] Ji, M., Rong, X., Wu, Y., Li, H., Zhao, X., Zhao, Y., ... & Li, B. (2025). Effects of Fermented Liquid Feed with Compound Probiotics on Growth Performance, Meat Quality, and Fecal Microbiota of Growing Pigs. *Animals*, *15*(5), 733.

[71] Elhalis, H. (2024). Expanding the Horizons of Saccharomyces cerevisiae: Nutrition, Oenology, and Bioethanol Production. *Sustainability*, *16*(24), 11151.

Nanotechnology for Biotic and Abiotic Stress Management and Soil Health

Indrani Debasmita Borah[1*], Shibani Ritusmita Borah[2], Deep Jyoti Das[3]

[*1]Department of Agronomy, Assam Agricultural University, Jorhat, Assam, 785013
[2]Department of Plant Breeding and Genetics, Assam Agricultural University, Jorhat, Assam, 785013
[3]School of Natural Resource Management, College of Postgraduate Studies in Agricultural Sciences, Central Agricultural University-Imphal, Umiam-793103, Meghalaya, India
*Corresponding Author

Received:- 11 April 2025/ Revised:- 16 April 2025/ Accepted:- 22 April 2025/ Published: 30-04-2025

***Abstract*—** *Nanotechnology has emerged as a revolutionary approach in agriculture, offering innovative solutions for managing biotic and abiotic stresses while simultaneously promoting soil health. Plants are constantly exposed to a variety of biotic (living) and abiotic (non-living) stresses in their environment. Biotic stresses, primarily caused by pathogens such as bacteria, fungi, viruses, and pests, pose substantial challenges to global food security. Nanotechnology offers precise tools for disease management through the development of nanoherbicides, nanofungicides and nanoemulsions. Abiotic stresses, including drought, salinity, heavy metals, and extreme temperatures, exert detrimental effects on crop productivity. Nanomaterials, such as nanosensors and nanofertilizers, play a pivotal role in alleviating these stressors by improving nutrient and water use efficiency. Nanosensors facilitate real-time monitoring of environmental conditions, allowing for precise and timely interventions. Nanofertilizers, on the other hand, enable controlled nutrient release, reducing wastage and minimizing adverse environmental impacts. Nanotechnology guarantees site-specific delivery of nutrients to the specific region within the plant, minimizing losses and enhancing effectiveness. The smaller dimensions of nanomaterials provide a larger surface area for pesticides and fertilizers, increase their bioavailability, significantly improve disease and pest management in crops, and effectively address the limitations associated with conventional pesticide application. Also, the creation of nano enzymes has transformed the way plants manage stress, as they function as highly effective antioxidant enzymes. These nano enzymes have gained significant traction in combating salinity tolerance in recent times. For instance, cerium oxide nanoparticles (nanoceria) coated with polyacrylic have demonstrated efficient elimination of hydroxyl radicals. In addition to stress management, nanotechnology also contributes to enhancing soil health. Nanoparticles and nanocomposites improve soil structure, water retention, and nutrient availability. Furthermore, the enhanced mobility of nutrients in nanoscale formulations minimizes leaching and runoff, reducing the risk of water pollution. Nanotechnology represents a promising paradigm in agriculture for managing biotic and abiotic stresses, enhancing soil health, and ensuring sustainable crop production.*

Keywords*— *Nanotechnology in agriculture, Biotic stress management, Abiotic stress management, Soil health, Nanofertilizers, Nanosensors, Nanopesticides, Nanoherbicides, Nanozymes, Nanomaterials.

I. INTRODUCTION

As per the National Nanotechnology Initiative (NNI), nanotechnology involves the understanding, engineering, and practical application of materials on a nanoscale, typically ranging from 1 to 10 nanometres in size. The concept of "nanobiotechnology" was initially coined by biophysicist Lynn W. Jelinski at Cornell University in the United States. Nanoparticles (NPs) have a considerably high surface energy and an elevated surface-to-volume ratio, factors that boost their reactivity and biochemical activity. Nanotechnology presents a unique opportunity to pioneer novel tools and technologies for the investigation and manipulation of biological systems. Its expansive reach extends across various domains and offers a broad spectrum of applications, particularly within the realms of biotechnology and the agricultural sector.

Plants, being immobile organisms, continuously confront environmental fluctuations and various stressors, either individually or in combination, throughout their lifespan. Despite this, plants have evolved diverse mechanisms to combat unfavourable conditions. Remarkably, the way they respond can exhibit significant variations, even among members of the same plant species. The biotic and abiotic stresses are significant constraints that have a detrimental impact on crop productivity and the growth of plants. In the current scenario, agriculture confronts its most significant challenges, including pests, climate change, and a reduction in the availability of essential nutrients. Worldwide, approximately 22,000 various plant pathogens, weeds, insects, and mites exert their influence on farming (Zhang *et al.*, 2021). Not all crop plants possess inherent resistance genes against pathogenic diseases, making their need for external support more critical compared to genetically modified crops. Micronutrients such as copper (Cu), manganese (Mn), and zinc (Zn) play essential roles in initiating enzyme activities and generating biomolecules that contribute to plant defense mechanisms. Consequently, the pursuit of a more sustainable alternative remains one of the most formidable challenges in agriculture, intending to enhance crop production and effectively manage plants against diseases and pest attacks. (Adisa *et al*., 2019). The utilization of engineered nanomaterials (ENMs) has garnered significant attention in the context of both plant stress management and the improvement of soil fertility. It has emerged as a powerful tool in agriculture, offering innovative solutions to address biotic and abiotic stress in crops while promoting soil health. In this chapter, we will explore the applications of nanotechnology in managing these stresses and improving soil quality. We will delve into the mechanisms involved, the latest advancements, and the potential challenges and ethical considerations.

The application of fertilizers in agriculture is a common practice aimed at increasing productivity to meet the growing demand for food. Fertilizers play a crucial role in supporting crop growth, development, and production. However, a significant portion of applied fertilizers often goes unused by plants due to various factors such as leaching in soil and degradation by processes like photolysis, hydrolysis, and decomposition. Despite the necessity of fertilizers for agriculture, managing their application and ensuring efficient utilization remains a challenge for farmers and agricultural experts (Singh *et al.,* 2016). The application of nanofertilizers emerges as a promising alternative to enhance resource use efficiency in agriculture while addressing the issue of increased soil toxicity associated with the accumulation of chemical fertilizers and pesticides. Nanofertilizers, characterized by their nano-sized particles, offer improved nutrient delivery and increased plant absorption, resulting in enhanced crop yields. Unlike traditional chemical fertilizers, nanofertilizers may mitigate the problem of unutilized nutrients, as their nanoscale properties can enhance nutrient availability for plants. Furthermore, the use of nanofertilizers has the potential to alleviate soil toxicity concerns by minimizing the accumulation of conventional fertilizers in the soil. This innovative approach could contribute to sustainable agriculture by optimizing nutrient utilization, reducing environmental impacts, and promoting soil health (DeRosa *et al.,* 2010 and Nair *et al*., 2010).

II. BIOTIC STRESS IN PLANTS

Biotic stress results from interactions with living organisms, such as pests, pathogens, and herbivores. These stressors can have devastating effects on plant health and crop yield:

1) **Pests:** Insects, mites, and other herbivores feed on plant tissues, causing damage by consuming leaves, stems, and roots. They can also transmit diseases, further compromising plant health.

2) **Pathogens:** Bacteria, fungi, viruses, and other microorganisms can infect plants, leading to diseases that weaken or kill them. Plant pathogens can spread rapidly and devastate entire crops if not managed effectively.

3) **Weeds:** Although not usually considered pests, invasive plants (weeds) compete with cultivated crops for resources, including water, nutrients, and sunlight, leading to reduced crop productivity.

III. ABIOTIC STRESS IN PLANTS

Abiotic stressors are non-living environmental factors that can adversely affect plant growth and development. Common abiotic stressors include:

1) **Drought:** Insufficient water availability can lead to reduced turgor pressure, stomatal closure, and impaired photosynthesis, resulting in wilting and decreased growth.

2) **Salinity:** High soil salt concentrations can disrupt water uptake by plants, leading to osmotic stress and ion toxicity. Salt-affected soils are challenging for agriculture.

3) **Temperature Extremes:** Extreme cold or heat can disrupt cellular processes and damage plant tissues. Frost can be harmful to sensitive crops.

4) **Nutrient Deficiency/Toxicity:** Imbalances in essential nutrients can lead to nutrient deficiencies or toxicities, affecting plant health and yield.

5) **Heavy Metals:** Contaminated soils with heavy metals like lead, cadmium, and mercury can accumulate in plant tissues, posing a threat to both plants and consumers.

Among abiotic stresses, factors such as drought, salinity, alkalinity, submergence, and mineral toxicity/deficiencies are recognized as significant contributors to decreased crop growth and productivity. Among these abiotic stresses, salinity, drought, and low temperature are identified as the primary factors leading to substantial reductions in crop yield. Plants respond to abiotic stress through various adaptive mechanisms. These include altering their physiological processes, adjusting root architecture, and accumulating compatible solutes to maintain cellular osmotic balance. Additionally, some plants exhibit stress tolerance through genetic adaptations, which can be exploited in breeding programs.

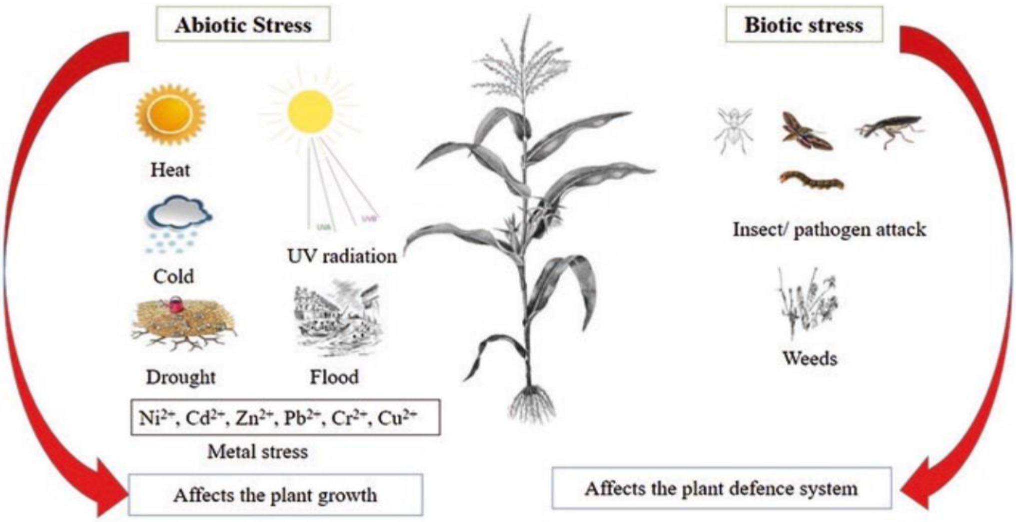


FIGURE 1: Various abiotic and biotic stress factors impact the growth and defense mechanisms of plants.

IV. MECHANISMS

Under abiotic stress conditions, various reactive oxygen species (ROS) are generated, including hydrogen peroxide (H_2O_2), hydroxyl radical (OH^-), superoxides (O_2^-), singlet oxygen species ($1O_2$), and hydroperoxy radical (HO_2). These reactive oxygen species (ROS) instigate harmful effect to cells and genes (Shen *et al*., 2010) and trigger a series of cell signalling events and influencing the activation or inhibition of numerous gene expressions for defense mechanisms.

TABLE 1
KEY ENZYMATIC AND NON-ENZYMATIC ANTIOXIDANTS INVOLVED IN PLANT ROS SCAVENGING UNDER ABIOTIC STRESS

Enzymatic antioxidants	Superoxide dismutase (SOD)
	Catalase (CAT)
	Ascorbate peroxidase (APX
	Glutathione reductase (GR)
Non-enzymatic antioxidants	Glutathione
	Ascorabate

V. NANOPARTICLES IN BIOTIC AND ABIOTIC STRESS MANAGEMENT:

The synthesis of nanoparticles can be achieved through various methods, including physical, chemical, and biological approaches. While chemical synthesis has been a predominant method, there is a growing emphasis on biological synthesis, often referred to as green synthesis, using plants or their extracts. Plants, regardless of being herbs, shrubs, or trees, contain a variety of compounds such as enzymes, sugars, proteins, and phytochemicals like flavonoids, latex, phenolics, terpenoids, alcohols, amines, and cofactors. These compounds play a crucial role as reducing and stabilizing agents during the synthesis of metallic nanoparticles from metal salts. The utilization of plant-based materials in nanoparticle synthesis is considered an eco-friendly approach, offering controlled synthesis with a well-defined size and shape. This not only provides a sustainable solution but also helps prevent atmospheric pollution, making it a promising avenue for the development of nanoparticles with diverse applications (Kumar *et al*., 2009; Sharma *et al*., 2009; Siddiqui *et al*., 2014). Numerous studies have highlighted that the impact of nanoparticles on plant growth and development is concentration-dependent. The concentration of nanoparticles applied can influence the nature and extent of their effects on plants. Interestingly, nanoparticles have been found to upregulate the activities of antioxidant enzymes such as superoxide dismutase (SOD), catalase (CAT), and peroxidase (POD). These antioxidant enzymes play a crucial role in mitigating oxidative stress and maintaining cellular homeostasis. The concentration-dependent responses suggest that careful consideration and optimization of nanoparticle concentrations are essential in harnessing their beneficial effects on plant growth while minimizing potential adverse effects. This nuanced understanding is critical for the successful integration of nanoparticles in agricultural practices to enhance crop performance sustainably Laware *et al*., 2014)

Silicon nanoparticles: Silicon (Si) is abundantly present in the soil and Earth's crust, playing a crucial role in plant defense and growth. Silicon nanoparticles have gained attention for their ability to effectively disperse over a wide area. For example, it is estimated that 1.0 gram of silica nanoparticles with a diameter of 7.0 nm can provide a wide absorption surface equal to 400 m^2. Additionally, silica nanoparticles influence xylem humidity, water translocation, and enhance turgor pressure in plants. This results in increased leaf relative water content and water use efficiency, ultimately contributing to improved plant health and productivity. (Wang *et al*., 1994; Rawson *et al.*, 1988). Studies have shown that silica nanoparticles (SNPs) can enhance plant growth and yield, particularly under stress conditions. This improved tolerance may be attributed to the absorption of silicon nanoparticles by plant roots. Once absorbed, SNPs can develop a fine layer within the plant cell wall, providing structural support that helps plants resist various stresses. By reinforcing the cell wall, SNPs assist in maintaining plant yield even when faced with environmental challenges such as drought, salinity, or disease. This mechanism highlights the potential of silica nanoparticles as a valuable tool for enhancing crop resilience and productivity in agricultural settings (DeRosa *et al*., 2010).

Zinc oxide nanoparticles: Micronutrient fertilizers have been shown to enhance plant tolerance to environmental stresses such as drought and salinity. Zinc (Zn) is one such important micronutrient necessary for the optimal growth and development of plants. It facilitates vital metabolic reactions within plants, promoting their growth and development. In addition to its primary role in plant growth, zinc also plays a crucial role in reducing the uptake of toxic heavy metals by plants. This function helps protect plants from heavy metal toxicity, such as cadmium (Cd), by limiting their absorption from the soil. By providing adequate zinc through fertilization, growers can not only support healthy plant growth but also mitigate the risks associated with heavy metal contamination in agricultural environments (Baybordi*et al*., 2005). Zinc oxide (ZnO) nanoparticles have been found to have a stimulating effect on the auxin (indole-3-acetic acid, IAA) levels in plant roots or sprouts. Auxins are crucial plant hormones responsible for promoting and regulating various aspects of plant growth and development, including cell elongation, root development, and overall plant architecture. The increased auxin levels induced by ZnO nanoparticles contribute to the promotion of plant growth. This suggests that ZnO nanoparticles can potentially serve as a growth-promoting agent by modulating hormone levels in plants, providing an avenue for optimizing plant development in agricultural and horticultural practices.

Titanium dioxide nanoparticles: Titanium dioxide (TiO_2) nanoparticles exhibit photocatalytic properties, initiating oxidation-reduction reactions that generate superoxide anion radicals and hydroxides when exposed to light. Interestingly, despite this inherent photocatalytic nature, photosterilization by TiO_2 nanoparticles has been found to positively impact plant growth and development. Studies have indicated that TiO_2 nanoparticles, particularly in the rutile phase, enhance antioxidant stress tolerance in plants. This is achieved by modulating various processes, including reducing the accumulation of superoxide radicals, hydrogen peroxide, malonyldialdehyde (MDA) content, and inducing the activities of antioxidant enzymes within plants. Enzymes such as superoxide dismutase, catalase, ascorbate peroxidase, and guaiacol peroxidase are influenced by the photochemical reactions occurring in the chloroplasts of plants like Spinacia oleracea. The findings suggest that TiO_2 nanoparticles can play a role in enhancing plant stress tolerance and antioxidant defense mechanisms (Lei, 2010).

VI. BIO-PRIMING FOR ALLEVIATING BIOTIC AND ABIOTIC STRESS

Bio-priming serves as a highly efficient means of administering biocontrol agents, with priming being recognized as an optimal approach for triggering resistance mechanisms. This method enhances the effectiveness of rhizobacteria-induced resistance in plants. Trichoderma harzianum is extensively utilized for bio-priming due to its broad spectrum of antagonistic activity against various plant pathogens, particularly fungi and nematodes(Singh *et al*., 2005).Symbiotic fungi, specifically vesicular-arbuscular mycorrhiza (VAM), including species such as *Acaulospora* sp., *Ambispora* sp., *Gigaspora* sp., *Glomus* sp., *Pacispora*sp., and *Paraglomus*sp., have demonstrated significant effects on plant nutrient absorption, growth, and an impressive ability to withstand abiotic stress, particularly during drought conditions (Oliveira *et al*., 2006).

Several mechanisms have been proposed for the microbial-induced enhancement of abiotic stress tolerance in plants. Symbiotic stress tolerance in plants involves two key mechanisms: firstly, the activation of host stress response systems immediately upon exposure to stress, enabling plants to avoid or mitigate stress impacts (Schulz *et al.*,1999); secondly, the biosynthesis of anti-stress biochemicals by endophytes (Miller *et al*., 2002; Schulz *et al*., 2002). The manifestation of this biosynthesis leads to various mechanisms, such as osmotic adjustment, which imparts tolerance to abiotic stresses. Osmotic adjustments, achieved through an enhanced production of osmolytes, result in increased water retention within cells, thereby improving the water use efficiency of the plant. The higher concentration of osmolytes in plant cells contributes to increased cell wall elasticity and an elevated turgid weight to dry weight ratio (TW/DW). Endophytes play a role in synthesizing alkaloids such as lolines, which provide osmotic protection by reducing stomatal conductance and alleviating drought stress (Morse *et al.*, 2002). These alkaloids serve to protect macromolecules from denaturation and/or reactive oxygen species (ROS) associated with drought stress (Schardl *et al*., 2004).

VII. NANOPESTICIDE IN BIOTIC STRESS MANAGEMENT

Nanopesticides, formulated by encapsulating conventional pesticides within nanoparticles, represent a breakthrough in pest management. They offer several advantages, such as controlled release, reduced environmental impact, and enhanced efficacy. Nanopesticides minimize off-target effects, making them environmentally friendly. Furthermore, they can be designed to release pesticides in response to specific triggers, like pH or temperature, ensuring targeted pest control. Silver nanoparticles, for instance, have exhibited excellent antimicrobial properties against various plant pathogens, while carbon-based nanoparticles can serve as carriers for pesticide delivery.

VIII. NANOENCAPSULATION OF BIOCONTROL AGENTS

Nanoencapsulation also extends to beneficial microorganisms used in biological control. Encapsulating biocontrol agents within nanoparticles protects them from harsh environmental conditions, improves their stability, and enhances their colonization on plant surfaces. This approach fosters a more sustainable and eco-friendly means of managing plant diseases and pests.

Nanoencapsulation involves the encapsulation of biocontrol agents, such as beneficial microorganisms or natural compounds, within nano-sized particles. This technique offers several advantages for the delivery of biocontrol agents in agriculture. Firstly, nanoencapsulation protects the biocontrol agents from environmental degradation, such as UV radiation or enzymatic degradation, prolonging their shelf life and viability. Additionally, nanoencapsulation enables the controlled release of the biocontrol agents, ensuring a sustained and targeted delivery to the desired site of action, such as the rhizosphere or phyllosphere of plants. This enhances the efficacy of biocontrol agents in suppressing plant pathogens or pests while minimizing off-target effects. Moreover, nanoencapsulation can improve the stability and solubility of biocontrol agents, enhancing their compatibility with agricultural formulations and facilitating their application through various delivery systems, including foliar sprays, seed treatments, or soil drenches. Overall, nanoencapsulation holds great potential for enhancing the efficacy, stability, and delivery of biocontrol agents in integrated pest management strategies, contributing to sustainable and environmentally-friendly agricultural practices.

IX. NANOTECHNOLOGY FOR ABIOTIC STRESS MANAGEMENT

9.1 Nanosensors for Environmental Monitoring:

Nanosensors play a pivotal role in assessing soil conditions and responding to abiotic stressors. These tiny devices can detect variations in soil moisture, salinity, and nutrient levels at high precision. Farmers can receive real-time data, enabling them to make informed decisions about irrigation and nutrient application, which is vital in drought-prone regions. Nanosensors can also detect heavy metal contamination in soil, allowing for early intervention to prevent soil degradation. Nanosensors offer a powerful tool for real-time monitoring of stress factors in crops, enabling timely interventions and precise management strategies as follows:

1) **Early Detection:** Nanosensors can detect subtle changes in plant physiology, such as alterations in hormone levels, chlorophyll fluorescence, or reactive oxygen species production, which serve as early indicators of stress. Early detection allows farmers to take proactive measures to mitigate stress before visible symptoms appear.

2) **Environmental Monitoring:** Nanosensors can measure various environmental parameters, including temperature, humidity, light intensity, and soil moisture content, which influence plant stress levels. By continuously monitoring these factors, nanosensors provide valuable insights into the environmental conditions affecting crop health and productivity.

3) **Nutrient Status Monitoring:** Nanosensors can measure nutrient levels in soil and plant tissues, providing real-time information on nutrient availability and uptake efficiency. This enables precise fertilizer application tailored to the specific needs of crops, reducing nutrient waste and minimizing environmental impacts.

4) **Water Stress Monitoring:** Nanosensors can detect changes in soil moisture levels and plant water status, enabling accurate assessment of water stress in crops. This information allows for optimized irrigation scheduling and efficient water management practices, conserving water resources and improving crop resilience to drought.

5) **Disease and Pest Detection:** Nanosensors can identify the presence of pathogens, pests, and their associated biomolecules in crops, facilitating early detection of diseases and pest infestations. Early detection enables timely implementation of control measures, such as targeted pesticide application or quarantine procedures, to prevent yield losses.

6) **Stress Response Monitoring:** Nanosensors can monitor plant responses to stress at the molecular level, including the expression of stress-related genes, synthesis of stress-responsive proteins, and accumulation of stress-induced metabolites. This information provides insights into the mechanisms underlying plant stress tolerance and informs breeding efforts to develop stress-resistant crop varieties.

7) **Data Integration and Analysis:** Nanosensors generate large amounts of data that can be integrated with other agricultural data sources, such as remote sensing imagery, weather forecasts, and agronomic databases. Advanced data analytics techniques, including machine learning and predictive modelling, can process this data to identify patterns, predict stress events, and optimize management decisions.

By providing real-time, site-specific information on crop stress factors, nanosensors enable precision agriculture practices that optimize resource use, minimize input costs, and maximize crop yields while promoting environmental sustainability. Continued research and development in nanosensor technology are essential to enhance sensor performance, scalability, and affordability for widespread adoption in agriculture.

9.2 Nanoparticles for Soil Remediation:

Contaminated soils are a global concern, with heavy metals being one of the most common pollutants. Nanoparticles like zero-valent iron (nZVI) have shown remarkable potential for remediating heavy metal-contaminated soils. These nanoparticles can immobilize or transform toxic heavy metals into less harmful forms, restoring soil health. Additionally, nanomaterials can enhance nutrient availability by increasing nutrient retention and slow release, reducing the need for excessive fertilization.

9.3 Carbon nanotubes:

Carbon nanotubes (CNTs) have emerged as promising tools for mitigating abiotic stresses in crops due to their unique physicochemical properties and versatile applications. The mechanism underlying the role of CNTs in abiotic stress management involves several key factors. Firstly, CNTs possess high surface area and exceptional mechanical strength, which enable them to serve as carriers for various biologically active compounds such as antioxidants, Osmo protectants, and growth-promoting substances. These compounds can help alleviate abiotic stress-induced damage by scavenging reactive oxygen species (ROS), stabilizing cell membranes, and regulating osmotic balance in plants.

Moreover, CNTs exhibit excellent electrical conductivity and thermal stability, allowing them to act as nanoscale electrodes for enhancing electron transfer processes in plants. This facilitates the activation of stress-responsive signalling pathways and the induction of stress tolerance mechanisms, such as the synthesis of stress-related proteins and the accumulation of compatible solutes. CNTs possess the ability to interact with soil particles and improve soil structure, porosity, and water retention capacity. This creates a conducive microenvironment for root growth and microbial activity, facilitating nutrient cycling and enhancing soil fertility. The multifaceted mechanisms of CNTs in abiotic stress management involve their roles as carriers for biologically active compounds, enhancers of electron transfer processes, facilitators of nutrient and water uptake, improvers of soil properties, and sensors for stress monitoring.

X. NANOTECHNOLOGY AND SOIL HEALTH

- Soil Nutrient Management: Nano-fertilizers, with their tailored nutrient release profiles, improve nutrient use efficiency. They ensure that plants receive essential nutrients precisely when needed, minimizing nutrient leaching and environmental pollution.
- Soil Microbial Activity: Nanotechnology also influences soil microbial communities positively. Nanostructures act as carriers for beneficial microorganisms, protect them from environmental stressors, and enhance their proliferation. This supports nutrient cycling and overall soil health.
- Soil Structure and Porosity: Nanoparticles can improve soil structure by reducing compaction and enhancing porosity. This leads to better aeration, water infiltration, and root penetration, ultimately improving soil fertility.

XI. CONCLUSION

Nanotechnology holds immense potential for revolutionizing agricultural practices by addressing the complex challenges of biotic and abiotic stresses while promoting soil health and sustainability. Through the development of innovative nanomaterials and nanodevices, researchers and agricultural practitioners can harness the unique properties of nanoparticles to enhance the resilience of crops against pests, diseases, drought, and other environmental stressors. Nanotechnology enables precise and targeted delivery of biocontrol agents, pesticides, and nutrients, thereby minimizing environmental impacts and optimizing resource utilization. Moreover, nanosensors provide real-time monitoring of soil health parameters and crop stress factors, facilitating data-driven decision-making and precision agriculture practices.

Furthermore, nanomaterials such as nano zero-valent iron (nZVI) contribute to soil remediation efforts by degrading pollutants and improving soil fertility, while nano-hydrogels enhance water retention and nutrient availability in soils. Additionally, nanoencapsulation techniques protect and deliver beneficial microorganisms and natural compounds, promoting sustainable pest management strategies. By leveraging the transformative potential of nanotechnology, we can pave the way toward a more resilient, efficient, and sustainable agricultural system for future generations.

REFERENCES

[1] Adisa, I. O., Pullagurala, V. L. R., Peralta-Videa, J. R., Dimkpa, C. O., Elmer, W. H., Gardea-Torresdey, J. L., & White, J. C. (2019). Recent advances in nano-enabled fertilizers and pesticides: a critical review of mechanisms of action. *Environmental Science: Nano*, *6*(7), 2002-2030.

[2] Baybordi, A. (2005). Effect of zinc, iron, manganese and copper on wheat quality under salt stress conditions. *Journal of water and Soil*, *140*, 150-170.

[3] DeRosa, M. C., Monreal, C., Schnitzer, M., Walsh, R., & Sultan, Y. (2010). Nanotechnology in fertilizers. *Nature nanotechnology*, *5*(2), 91-91.

[4] Kumar, V., & Yadav, S. K. (2009). Plant‐mediated synthesis of silver and gold nanoparticles and their applications. *Journal of Chemical Technology & Biotechnology: International Research in Process, Environmental & Clean Technology*, *84*(2), 151-157.

[5] Laware, S. L., &Raskar, S. (2014). Effect of titanium dioxide nanoparticles on hydrolytic and antioxidant enzymes during seed germination in onion. *Int. J. Curr. Microbiol. App. Sci*, *3*(7), 749-760.

[6] Lei, Z. (2010). Antioxidant stress is promoted by nano-anatase in spinach chloroplasts under UV-Beta radiation. *Biological trace element research*, 121, 69–79.

[7] Miller, J. D., Mackenzie, S., Mark, F. O. T. O., Adams, G. W., & Findlay, J. A. (2002). Needles of white spruce inoculated with rugulosin-producing endophytes contain rugulosin reducing spruce budworm growth rate. *Mycological Research*, *106*(4), 471-479.

[8] Morse, L. J., Day, T. A., & Faeth, S. H. (2002). Effect of Neotyphodium endophyte infection on growth and leaf gas exchange of Arizona fescue under contrasting water availability regimes. *Environmental and Experimental Botany*, *48*(3), 257-268.

[9] Nair, R., Varghese, S. H., Nair, B. G., Maekawa, T., Yoshida, Y., & Kumar, D. S. (2010). Nanoparticulate material delivery to plants. *Plant science*, *179*(3), 154-163.

[10] Oliveira, L. A., Porto, A. L., &Tambourgi, E. B. (2006). Production of xylanase and protease by Penicillium janthinellum CRC 87M-115 from different agricultural wastes. *Bioresource Technology*, *97*(6), 862-867.

[11] Rawson, H. M., Long, M. J., & Munns, R. (1988). Growth and development in NaCl-treated plants. I. Leaf Na+ and Cl-concentrations do not determine gas exchange of leaf blades in barley. *Functional Plant Biology*, *15*(4), 519-527.

[12] Schardl, C. L., Leuchtmann, A., & Spiering, M. J. (2004). Symbioses of grasses with seedborne fungal endophytes. *Annu. Rev. Plant Biol.*, *55*, 315-340.

[13] Schulz, B., Boyle, C., Draeger, S., Römmert, A. K., & Krohn, K. (2002). Endophytic fungi: a source of novel biologically active secondary metabolites. *Mycological research*, *106*(9), 996-1004.

[14] Schulz, B., Römmert, A. K., Dammann, U., Aust, H. J., & Strack, D. (1999). The endophyte-host interaction: a balanced antagonism. *Mycological Research*, *103*(10), 1275-1283.

[15] Sharma, V. K., Yngard, R. A., & Lin, Y. (2009). Silver nanoparticles: green synthesis and their antimicrobial activities. *Advances in colloid and interface science*, *145*(1-2), 83-96.

[16] Shen, X., Zhou, Y., Duan, L., Li, Z., Eneji, A. E., & Li, J. (2010). Silicon effects on photosynthesis and antioxidant parameters of soybean seedlings under drought and ultraviolet-B radiation. *Journal of plant physiology*, *167*(15), 1248-1252.

[17] Siddiqui, M. H., Al-Whaibi, M. H., Faisal, M., & Al Sahli, A. A. (2014). Nano-silicon dioxide mitigates the adverse effects of salt stress on Cucurbita pepo L. *Environmental toxicology and chemistry*, *33*(11), 2429-2437.

[18] Singh, J., & Lee, B. K. (2016). Influence of nano-TiO2 particles on the bioaccumulation of Cd in soybean plants (Glycine max): A possible mechanism for the removal of Cd from the contaminated soil. *Journal of environmental management*, *170*, 88-96.

[19] Singh, U. S., Zaidi, N. W., Joshi, D., Khan, T., John, D., & Bajpai, A. (2005). Trichoderma: a microbe with multifaceted activity. *Annual Review of Plant Pathology (Vol. 3)*, *3*, 33-75.

[20] Wang, J., & Naser, N. (1994). Improved performance of carbon paste amperometric biosensors through the incorporation of fumed silica. *Electroanalysis*, *6*(7), 571-575.

[21] Zhang, X., & Zhang, Y. (2021). Experimental study on enhanced heat transfer and flow performance of magnetic nanofluids under alternating magnetic field. *International Journal of Thermal Sciences*, *164*, 106897.

A Study on the Relationship between Grower Characteristics and Adoption of Sugarcane Practices

Manish Mavaliya[1*], Dr. Jahanara[2], Balram Chopra[3]

[*1]M.Sc, Department of Agricultural Extension and Communication, Sam Higginbottom University of Agriculture, Technology & Sciences, Prayagraj, Uttar Pradesh, India
[2]Professor, Department of Agricultural Extension and Communication, Sam Higginbottom University of Agriculture, Technology & Sciences, Prayagraj, Uttar Pradesh, India
[3]Department of Agricultural Extension and Communication, Sam Higginbottom University of Agriculture, Technology & Sciences, Prayagraj, Uttar Pradesh, India
*Corresponding Author

Received:- 12 April 2025/ Revised:- 19 April 2025/ Accepted:- 27 April 2025/ Published: 30-04-2025

Abstract— *The study was conducted in Sri Ganganagar district of Rajasthan, selecting Sri Ganganagar and Sri Karanpur tehsils due to their extensive sugarcane cultivation. With support from agriculture and revenue officials, five major sugarcane-growing villages from each tehsil were identified, totaling ten villages. A categorized list of small, marginal, and large farmers was prepared with help from village Patwaris and agricultural supervisors. From this, 120 sugarcane growers were randomly selected to serve as respondents for the investigation. The study found that 58.33per cent of respondents had a medium level of adoption, 25per cent had a high level, and 16.66per cent had a low level. The highest adoption was seen in practices requiring less expertise, such as recommended spacing (80.83per cent) and harvesting methods (80per cent). However, lower adoption was observed in seed treatment (38.33per cent) and soil treatment for disease prevention (36.67per cent). A significant positive relationship was found between annual income and landholding, while age, education, family type, and size showed no significant impact on adoption.*

Keywords— Adoption levels, sugarcane farmers, recommended practices, correlation and factors influencing adoption.

I. INTRODUCTION

Agriculture is the backbone of the Indian economy, employing nearly two-thirds of the country's workforce and contributing 16.1per cent to the Gross Domestic Product (GDP). Despite a gradual decline in its share of GDP, agriculture remains vital due to its vast geographical coverage occupying around 43per cent of India's land area—and its role in ensuring food security, economic growth, and rural development. Among the diverse array of crops cultivated in India, sugarcane (*Saccharum officinarum* L.) holds a prominent position as one of the most significant commercial crops, with wide applications ranging from sugar production to bio-based industries. Contributes approximately 60per cent to the global sugar production, with India being one of the top producers. It is cultivated primarily in tropical and sub-tropical regions, making large parts of India including the northern plains and southern plateau ideal for its growth. It serves as a raw material for producing white sugar, jaggery (gur), and khandsari, and is also consumed directly through juice and chewing. The sugar industry, being a significant agro-based sector, contributes to employment, rural development, and foreign exchange savings. Over time, sugarcane has become a key cash crop, offering considerable economic opportunities to Indian farmers. Historically, the productivity of sugarcane in India has shown a steady increase from 56 tonnes per hectare in 1950–51 to 74.4 tonnes per hectare in 2017–18 due to advancements in production technologies, improved varieties, and better agronomic practices. Despite these gains, the actual yields are still far below the potential yield, which is more than double the current national average of 5.82 tonnes/ha. The yield gap is attributed to various constraints including climatic variability, suboptimal adoption of modern technologies, poor pest and disease management, inefficient marketing systems, and socio-economic challenges. A notable concern is the limited adoption of the recommended package of practices developed by research institutes. While extensive research has generated viable and productive sugarcane technologies, many innovations remain confined to research stations, with minimal transfer to the field level. This gap between technology development and adoption is particularly evident in states like Rajasthan, where sugarcane cultivation though geographically suitable and productive in districts such as Sriganganagar, Bundi, and Chittorgarh faces numerous agronomic and institutional challenges. For sustainable improvement in sugarcane production and productivity, it is critical to evaluate the level of adoption among farmers, the level of knowledge of improved practices, and the constraints impeding technology diffusion. Understanding these dynamics will not only help optimize production but also uplift the socio-economic status of sugarcane growers, contribute to rural livelihoods, and enhance national sugar output. This study, therefore, seeks to assess the current status of sugarcane cultivation practices, analyze adoption barriers, and provide actionable insights for researchers, extension workers, and policymakers to realign strategies for effective technology dissemination and industry modernization.

II. RESEARCH METHODOLOGY

The current research was carried out in the Sri Ganganagar district of Rajasthan, which comprises a total of ten tehsils. Among these, Sri Ganganagar and Sri Karanpur tehsils were purposively selected based on having the largest area dedicated to sugarcane cultivation. To identify the study locations, a detailed list of prominent sugarcane-producing villages within the selected tehsils was compiled with assistance from officials in the revenue and agriculture departments. From this list, five villages in each tehsil were chosen, focusing on those with the highest sugarcane cultivation area, resulting in a total of ten villages selected for the study. For respondent selection, a categorized list of small, marginal, and large sugarcane farmers was developed with the support of the local village Patwaris and agricultural supervisors. Based on this classification, a sample of 120 sugarcane growers was selected to participate in the study, ensuring representation from various farm sizes and socio-economic backgrounds. To assess adoption, responses were recorded on a three-point scale (fully, partially, not adopted) with scores of 3, 2, and 1. The adoption gap was calculated by subtracting the mean score from 100per cent. The study aimed to examine the relationship between personal attributes (age, education, landholding, family size, and family type) and the adoption of improved sugarcane production technology using correlation analysis at 5% and 1% significance levels.

III. RESULTS AND DISCUSSION

3.1 Adoption level:

As shown in Table 1, out of 120 most of the respondents (58.33per cent) had a medium level of adoption, followed by 25per cent with a high level and 16.66per cent with a low level. This indicates that the majority of farmers adopted the recommended practices to a moderate extent. Fewer farmers showed either high or low adoption. These findings are in line with the results reported by Maraddi (2006) and Joshi et al. (2007–08).

TABLE 1
DISTRIBUTION OF RESPONDENTS ON THE BASIS OF THEIR ADOPTION LEVEL

Adoption level	Frequency	Percentage
Low (22-27)	20	16.66
Medium (28-33)	70	58.33
High (34-37)	30	25.00
Total	**120**	**100.00**

3.2 Extent of adoption of respondents about improved sugarcane cultivation technology:

The study assessed the adoption levels of 17 key practices among sugarcane growers, as shown in Table 2. The mean and mean percentage scores for each practice were calculated, along with the adoption gaps. The results revealed that the highest adoption was observed in practices requiring less specialized skills, such as using recommended spacing (80.83per cent), recommended harvesting methods (80per cent), and following the recommended seed rate (78.33per cent). On the other hand, practices with lower adoption included proper seed treatment (38.33per cent), soil treatment for disease prevention (36.67per cent), timely fertilizer application (30.83per cent), and micro-nutrient doses (17.5per cent). These low adoption rates were attributed to factors such as lack of knowledge and the high cost of inputs like micro-nutrients, which hindered farmers from fully implementing these practices. These findings align with previous studies by Maraddi (2006) and Teeluck et al. (2007).

TABLE 2
EXTENT OF ADOPTION OF RESPONDENTS ABOUT IMPROVED SUGARCANE CULTIVATION TECHNOLOGY.

S. No	Practice	Frequency	Percentage	Rank
1.	Adopting improved sugarcane varieties	84	70	VII
2.	Using proper soil treatment to prevent the soil born diseases	44	36.67	XV
3.	Following recommended seed rate	94	78.33	III
4.	Using recommended spacing (*i.e*. PXP, RXR)	97	80.83	I
5.	Following recommended depth of sowing	89	74.16	V
6.	Using proper seed treatment to prevent the seed borne diseases	46	38.33	XIV
7.	Using recommended time of sowing	83	69.17	VIII
8.	Following recommended method of sowing	77	64.16	IX
9.	Using nitrogenous fertilizers as per Recommendation	85	70.83	VI
10.	Using phosphatic fertilizers as per Recommendation	57	47.5	XIII
11.	Using recommended doses of micro-nutrients	21	17.5	XVII
12.	Timely fertilizer application as per Recommendation	37	30.83	XVI
13.	Adoption of herbicides for weed control	60	50	XII
14.	Using recommended irrigation management	91	75.83	IV
15.	Using recommended insecticides, their concentration and time of spray	70	58.33	X
16.	Using recommended fungicides, their concentration and time of application	63	52.5	XI
17.	Using recommended harvesting methods	96	80	II

3.3 Relationship between selected variables of sugarcane growers and their level of adoption of recommended package of practices:

The study examined the relationship between various factors of sugarcane growers (age, education, income, land holding, family size, family type) and their adoption of recommended practices using the coefficient of correlation (r). The results, as shown in Table 3, indicate a significant positive relationship between annual income and land holding with the level of adoption, at a 5% significance level. However, there was no significant relationship between age, education, family type and family size with the adoption of practices. Based on these findings, the null hypotheses for these factors were rejected, and the alternate hypotheses were accepted, indicating these factors did not significantly affect adoption. Similar conclusions were reported by Singh et al. (2008).

TABLE 3
RELATIONSHIP BETWEEN SELECTED VARIABLES OF SUGARCANE GROWERS AND THEIR LEVEL OF ADOPTION OF RECOMMENDED PACKAGE OF PRACTICES

S.No.	Independent variables	Correlation coefficient (r)
1.	Age	0.093 NS
2.	Education	0.044 NS
3.	Annual income	0.255**
4.	Land holding	0.522**
5.	Family size	0.032 NS
6.	Family type	0.016 NS

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

- **Age and Adoption**: There was no significant relationship (r = 0.093) between the farmers' age and their adoption of practices. Therefore, age did not influence the adoption process.
- **Education and Adoption**: Education also showed no significant relationship (r = 0.044) with adoption levels. Despite farmers' education, extension contact appeared to play a more important role in the adoption process.
- **Annual Income and Adoption**: A positive and significant relationship (r = 0.255**) was found between annual income and adoption. As farmers' income increased, their ability to purchase necessary inputs for farming improved, leading to higher adoption levels.
- **Land Holding and Adoption**: Land holding had a positive and significant relationship (r = 0.522**) with adoption. Farmers with larger land holdings had more resources and information, facilitating greater adoption.
- **Family Size and Adoption**: No significant relationship (r = 0.032) was observed between family size and adoption, indicating that family size had little influence on the adoption process.
- **Family Type and Adoption**: Similarly, family type showed no significant effect (r = 0.016) on adoption, as the adoption process is an individual decision.

IV. CONCLUSION

The study concluded that most sugarcane farmers in the area had a medium level of adoption of recommended practices, with fewer adopting high or low levels. While simple practices showed good adoption, more specialized techniques faced barriers like knowledge gaps and high input costs. Additionally, income and landholding size positively influenced adoption, while factors such as age, education, and family size had no significant effect. These findings highlight the need for targeted interventions to improve adoption of advanced practices.

REFERENCES

[1] Joshi, P.J., Chouhan, N.B. and Patel, K.F. (2007-08). Knowledge level of farmers about modern practices of cotton cultivation in Bhal area. Gujarat Journal of Extension Education 18-19: 65-67.

[2] Marradi G. N. (2006). analysis of sustainable cultivation practices followed by sugarcane growers in Karnataka state, P.hd. Thesis Univ. of Agril. Sci., Dharwad (India).

[3] Nagaraja MV. (2002). A study on knowledge of improved cultivation practices of sugarcane and their extent of adoption by farmers in Bhadra command area in Davanagere district, Karnataka state. Ph. D. Thesis, University of Agricultural Sciences, Dharwad.

[4] Pawar PP, Jadale UD, Shinde CB, Kale PV. (2005). Adoption of improved production technology on sugarcane farmers in Western Maharashtra. Cooperative Sugar;36(10):805-812.

[5] Singh, M.P., Sharma, B.K., Singh, S.P., Naval Singh and Surender Kumar. (2008). Indicators influencing production gap of sugarcane and wheat crops in Western Uttar Pradesh. *Journal of Farming Systems Research & Development* 14(1):78- 83.

[6] Teeluck, Rar, K.S. (2007). Problems and prospects of cotton cultivation in Srigangangar district of Rajasthan. M.Sc. (Ag.) Thesis, submitted to Maharana Pratap University of Agriculture and Technology, Udaipur.

Study the Seasonal Abundance of Diamondback Moth and Natural Enemies in Cauliflower

Mukesh Jakhar[1*]; Dr. S. K. Singh[2]; Suman Chopra[3]; Pinki Sharma[4]

[*1]M.Sc. (Ag.) student, Department of Entomology, Raja Balwant Singh college of Agriculture, Bichpuri, UP.
[2]Associate Professor Department of Entomology, Raja Balwant Singh college of Agriculture, Bichpuri, UP.
[3]Research scholar, Department of Plant Pathology, SKNAU Jobner Jaipur, Rajasthan
[4]Research scholar, Department of Plant Pathology, Rajasthan College of Agriculture, MPUAT, Udaipur-313001
*Corresponding Author

Received:- 14 April 2025/ Revised:- 20 April 2025/ Accepted:- 28 April 2025/ Published: 30-04-2025

Abstract— *The infestation of diamondback moth was started from the 2nd SMW and reached its peak in 8th SMW during the year. The maximum temperature showed significant positive correlation with larval population of diamondback moth. Coccinellid predator, Coccinella septempunctata L. was recorded as a major predator in cauliflower ecosystem which was maximum in the11th SMW of the year. The maximum and minimum temperature significant positive correlation with the population of C. septempunctata.*

Among different newer insecticides tested against diamondback, spinosad was found to be most effective which was found at par with indoxacarb. The insecticides, emamectin benzoate, chlorantraniliprole and fipronil were found moderately effective. The chlorfenapyr, acephate and pyridalyl were found least effective.

The maximum yield of cauliflower heads was registered in the plots treated with Spinosad 45 Sc, which was found at par with indoxacarb 14.5 Sc, the latter treatment was also non-significant with flubendiamide 39.35 Sc. The minimum yield was observed in pyridalyl 10 Ec and acephate 75 Sp. All the treatment were significantly superior over control. The order of yield revealed by different treatments was spinosad= indoxacarb≥ flubendiamide≥ emamectin benzoate≥ chlorantraniliprole≥ fipronil= chlorfenapyr› acephate= pyridalyl› control.

Keywords— Diamondback moth, Insecticides, Cauliflower, Spinosad.

I. INTRODUCTION

Cauliflower, *Brassica oleracea* var. *Botrytis* L. is one of the important cruciferous vegetable crops grown in India. It is grown more or less in all the states and used as salad, boiled vegetable, in curries, pickling as well as dehydrated vegetable. The nutritional value/ 100 g of Cauliflower, consists of carbohydrates 5.3 g, fat 0.2 g, protein 2.4 g, vitamins (thiamine or vitamin $B_1$0.1 mg, riboflavin or B_2 0.1 mg, niacin or vitamin B_3 0.5 mg, pantothenic acid or vitamin B_5 0.7 mg, folate or vitamin B_9 57.0 mg, vitamin C 46.4 mg, and vitamin K 16.0 mg), minerals (Ca 22.0 mg, Fe 0.4 mg, Mg 15.0 mg, Mn 0.2 mg, P 44.0 mg, K 303 mg, Na 30.0 mg, Zn 0.3 mg) (Copyright 2017 Nutrition Value org.). The total area under cultivation of Cauliflower, in India is 372 thousand hectares with an annual production to the tune of 8534 thousand tonnes with productivity of 18.3 metric tonnes (Anonymous-2013). The total area under cultivation of Cauliflower, in Rajasthan is 346 hectares with an annual production to the tune of 7588 tonnes (Anonymous-2010). China is major Cauliflower, producing country with 47 per cent of world followed by India with 12 per cent of world production (FAO-2012).

The yield of Cauliflower is adversely affected by many bottlenecks including insect pest, diseases, environmental stresses, nutritional imbalance etc. Among them insect pests, *viz.*, tobacco caterpillar, *Spodoptera litura* (Fab.); diamondback moth, *Plutella xylostella* (L.); Cauliflower borer, *Hellula undalis* (Fab.); Cauliflower, looper, *Tricoplusiani* (Hub) and aphid, *Lipaphiserysimi* (Kalt.) (Prasad, 1963; Sachan and Srivastav, 1972; Joshi and Sharma, 1973; Mohan *et al*., 1981; Rao and Lal 2005). Out of these, aphid and diamondback moth are major pests causing significant loss in North India. The diamondback moth, *P. xylostella* was first reported on cruciferous vegetables in 1914 (Fletcher. 1914). It is sometimes called Cauliflower, moth, is a European moth believed to be originated in the Mediterranean region that has since spread worldwide. The moth has a short life cycle (14 days at 25 ^{0}C) is highly fecund, capable of migrating long distance, most important pest of cruciferous crops in the world that produces glucosinolates (Taleker and Shelton, 1993). The moth has a wing span of about 15 mm and body length of 6 mm. The forewings are narrow brownish grey with fine dark speckles. A creamy coloured stripe with a wavy edge of the posterior margin is sometimes constricted to form one or more light coloured diamond shapes, which is the basis of common name of the diamondback moth. The hind wings are narrow, pointed towards the apex and light grey with a wide fringe. Moths are active usually at twilight and at night feeding on cruciferous plants but also fly in the afternoon during mass outbreak.

II. MATERIALS AND METHODS

2.1 Seasonal abundance of diamondback moth and natural enemies in cauliflower:

2.1.1 Layout and design:

In order to study the incidence of Diamondback moth and abundance of natural enemies in cauliflower ecosystem and to work out their relationship with prevailing weather parameters, the experiment was laid out in five plots of 2.25 x 2.25 m^2 size during *Rabi*, 2016-17. These plots were contiguous to each. The observations on the abundance of diamondback moth and natural enemies were recorded from very beginning of their appearance on plants till harvesting of the crop.

2.1.2 Observations:

During the present study, the crop was found to be abundantly infested with diamondback moth, *P. xylostella*. Among the natural enemies of insect pests of cauliflower, the coccinellid predator, *Coccinella septempunctata* L. was found in the field. Other natural enemies like *Cotesia plutellae* and Syrphid flies were present in traces only.

2.2 Diamondback moth, *Plutella xylostella* (L.):

In order to register the larval population of diamondback moth (DBM), direct visual counting method was used (Lal, 1998). Ten plants were selected randomly from each plot and the total larval population of the pest was recorded at weekly interval.

2.3 Natural enemies:

Coccinellid predator *C. septempunctata* was appeared as the major natural enemy in cauliflower ecosystem, its population was recorded on ten randomly selected plants per plot.

2.4 Statistical analysis:

The observations taken on the abundance of diamondback moth and their natural enemies in cauliflower ecosystem were correlated (simple correlation, r) with prevailing weather parameters, *viz*., maximum and minimum temperature.

III. RESULTS AND DISCUSSION

3.1 Seasonal abundance of diamondback moth and natural enemies in cauliflower:

In the present investigation, the seasonal abundance of diamondback moth of cauliflower was studied for the year, 2016-17 which will be helpful in preparing proper schedule for effective management of this pest. The study revealed that the cauliflower crop was infested by a major pest, diamondback moth, *P. xylostella*. This insect pest has also been reported as serious insect pest of cabbage crop by Sachan and Srivastava (1972), Kandoria et al. (1996), and Sharma (2004) who support the present findings. Among the natural enemies of pests only coccinellid predator *Coccinella septempunctata L.* was observed in the cabbage ecosystem which feeds on the aphids.

Diamondback moth was observed as major pest of cauliflower crop attacking throughout the growth stages of the crop. The present finding get support with that of Ahmad et al. (2012) and Meena and Singh (2012) who reported diamondback moth as regular and major pest of cauliflower. The infestation of pest on cauliflower crop was started from first week of January (02nd SMW) and reached to maximum (45.2 larvae /10 plants) in the third week of February (8th SMW) during the year, thereafter, population started declining. Khaire et al. (1987) observed peak population of diamondback moth in the first week of February. The peak population was observed at 28.60C maximum and 13.40C minimum temperature. The present finding is in partial conformity with that of Gera and Bhatnager (1992), Meena and Sharma (2003), Shukla and Kumar (2004) and Goud et al. (2006) who reported that the infestation of pest started from second week of November and reached to peak in the last week of January to first week of February.

The larval population of diamondback moth had significantly positive correlation with maximum temperature (r= 0.51) and non-significant correlation with minimum temperature. The studies showed that the incidence of diamondback moth was only affected by temperature. The present finding is in conformity by Ahmad et al. who reported that population of diamondback moth was positive correlated with maximum temperature. Contrary results were also reported by Sharma (2004) and Chaudhuri et al. (2001) who reported non-significant positive and significant positive correlation, respectively between the population of diamondback moth and temperature. Ahmad and Ansari (2010) observed that population of diamondback moth started to build up as soon as the cauliflower crop was transplanted. Ahmad et al. (2012) observed that maximum population at 310C which is more as compared to the present study.

Among the natural enemies *Coccinella eptempunctata L.*, a predator of aphid was found in abundance. The population of *C. eptempunctata* was maximum (20.2 /10 plants) in the second week of March (11th SMW). The population of *C. eptempunctata* had significantly positive correlation with maximum (r= 0.71) and minimum temperature (r= 0.66). The present findings are in agreement with that of Bhaskar and Virakatamath (2002), Shukla and Kumar (2003), Bar et al. (2004) observed the parasitisation of diamondback moth by *cotesia plutellae* which was lacking in the present study. Shukla and Kumar (2006) observed parasitisation of diamondback moth by *Tetrastiches Sokolowski* which was not evidence in the present study.

3.2 Seasonal abundance of diamondback moth and natural enemies in cauliflower:

In the present study, conducted during *Rabi*, 2016-17 the cauliflower crop *Brssicaoleracea*var. *Botrytis L* was found to be infested with diamondback moth, *P.xylostella* from 4thJanuary 2017 to 22nd March 2017. Among the natural enemies none of the species was recorded parasitizing the diamondback moth. However, the mynah bird was found predating the larvae. Coccinellid species dominating the cauliflower crop ecosystem was *Coccinella septempunctata* (L.) Other minor populations recorded were of *menochitus sexma culatatus*and syrphid fly. The population of diamond back moth and *C. septempunctata* have been registered.

3.3 Diamondback moth, *Plutella xylostella* (L.):

During *Rabi*, 2016-17, the larval population of diamondback moth first appeared in the 2nd standard meteorological week, SMW (2.0 larvae/ 10 plants) and reached to peak (45.2 larvae /10 plants) in the 8th meteorological week, SMW. The population level was at declining trend after 8th SMW and vanished in 13th meteorological week.

TABLE 1
SEASONAL ABUNDANCE OF DIAMONDBACK MOTH, *PLUTELLA XYLOSTELLA* (L.) AND NATURAL ENEMIES IN CAULIFLOWER CROP DURING *RABI*, 2016-17

S. No.	Date of observation	Standard meteorological week (SMW*)	Temperature(^{0}C)		Mean larval population of diamondback moth/ 10 plants	*C.septempunctata* population/10 plants
			Maximum	Minimum		
1	4/1/17	02	22.0	10.4	2.0	0.00
2	11/1/17	03	19.2	5.2	10.0	0.00
3	18/1/17	04	20.8	7.4	21.6	8.6
4	25/1/17	05	22.1	11.8	28.2	10.0
5	1/2/17	06	23.3	11.1	33.6	10.8
6	8/2/17	07	23.7	8.9	40.4	11.8
7	15/2/17	08	28.6	13.4	45.2	14.8
8	22/2/17	09	27.4	12.6	40.2	16.8
9	1/3/17	10	29.3	13.6	37.2	17.2
10	8/3/17	11	26.3	13.0	35.4	20.2
11	15/3/17	12	29.1	13.4	33.6	18.4
12	22/3/17	13	35.6	19.1	28.0	14.8

The peak larval population of diamondback moth, *P. xylostella* (45.2/ ten plants was observed at 28.6^{0}C maximum and 13.4^{0}C minimum temperatures, thereafter population started declining

The correlation analysis revealed that the larval population of diamondback moth had significant positive correlation with maximum (r = 0.51). b Whereas, non-significant correlation with minimum temperature.

3.4 Natural enemies:

Among the natural enemies, the ladybird beetle, *Coccinella septempunctata* has been recorded as the major natural enemy-pwhich predates the aphids in cauliflower ecosystem. In the year of experimentation, the population of *C. septempunctata* was first noticed in the 4thSMW (8.6/ ten plants) and reached to maximum in the 11thSMW (20.2/ ten plants) at 26.3^{0}C maximum and 13.0^{0}C minimum temperatures

The correlation studies revealed that during the year, the population of *C. septempunctata* had significant positive correlation with maximum and minimum temperature (r = 0.71 and r = 0.66, respectively). Thepopulation of *C. septempunctata* also had significant positive correlation with population of diamondback moth (r = 0.81).

TABLE 2
CORRELATION COEFFICIENT BETWEEN LARVAL POPULATION OF DIAMONDBACK MOTH, *PLUTELLA XYLOSTELLA* (L.), *COCCINELLA SEPTEMPUNCTATA* L. AND ABIOTIC FACTORS IN *RABI*, 2016-17

S. No.	Insect pests and natural enemy	Temperature (^{0}C)		C. septempunctata
		Maximum	Minimum	
1.	Diamondback moth, *Plutella xylostella* (r)	0.51*	0.43(NS)	0.85*
2.	*Coccinella septempunctata* (r)	0.71*	0.66*	----

**** Significant at the 5 % level of significance***

IV. CONCLUSION

Cauliflower, *Brassica oleracea* var. *Botrytis* L. is one of the important cruciferous vegetable crops grown in India. In the present study, conducted during Rabi, 2016-17 the cauliflower crop Brssica oleracea var. Botrytis L. was found to be infested with diamondback moth, *P.xylostella* from 4thJanuary 2017 to 22ndMarch 2017. Among the natural enemies none of the species was recorded parasitizing the diamondback moth. However, the mynah bird was found predating the larvae. Coccinellid species dominating the cauliflower crop ecosystem was Coccinella septempunctata (L.) Other minor populations recorded were of menochitus sexmacu latatus and syrphid fly. The correlation studies revealed that during the year, the population of C. septempunctata had significant positive correlation with maximum and minimum temperature (r = 0.71 and r = 0.66, respectively). The population of C. septempunctata also had significant positive correlation with population of diamondback moth (r = 0.81).

REFERENCES

[1] Anonymous, 2010. Directorate of Horticulture, Government of Rajasthan, Jaipur, Rajasthan.

[2] Ahmad, T. and Ansari, M. 2010. Studies on seasonal abundance of diamondback moth, *Plutella xylostella* on cauliflower crop. *Journal of Plant Protection Research,* 50 (3): 280-287.

[3] Ahmad, S.; Bibi, A.; Salman, M. Hussan, A. and Muhammad, N. 2012. Studies on seasonal abundance of diamondback moth, *Plutella xylostella (*Lepidoptera: Yponomeutidae) on cauliflower crop. Department of Plant Protection, University of Agriculture, Peshawar, Pakistan.

[4] Bar, U.K. Uma Shankar, Raju, S.V.S. 2001. Seasonal abundance and parasitization of diamondback moth and larval parasitoid, *Cotesia plutellae. Annals of Plant Protection Science,* 12 (2): 214-216.

[5] Bhaskar, H. and Viraktamath, C.A. 2002. Diversity and abundance of aphidophagous coccinellids in cabbage field. *Insect Environment*, 8 (1) : 31

[6] FAO. 2012. Annual vegetable production report, www. fao. org

[7] Fletcher, T.B. 1914. Some south Indian insect. Superintendent govt. press, Madras. 565 p.

[8] Chaudhuri, N.; Ghosh, S. and Senapati, S.K. 2001. Incidence of insect pests of cabbage in relation to prevailing climate conditions of terai region. *Indian Journal of Entomology*, 63 (4) 421-428.

[9] Gera, S.S. and Bhatnagar, K.N. 1992. Seasonal incidence of pest complex of cabbage and their control in a semi-arid region. *Pestology,* 16 (3) : 38-45.

[10] Goud, C.R. Rao, S.R.K. and Chiranjeevi, C.H. 2006. Influence of weather parameters on the population buildup of diamondback moth, *Plutella xylostella* (L.) infesting cabbage. *Pest management in Horticulture Ecosystem*, 12 (1): 103-106.

[11] Khaire, V.A. Lauvande, K.E. and Ajvi, D.S. 1987. Population dynamics of insect pests of cabbage. *Current Research*, 48 (2): 48-86.

[12] Kandoria, J.L. Lal, A. and Singh, L. 1996. Seasonal availability of diamondback moth, *Plutella xylostella* (L.) under Punjab conditions. *Journal of Insect Science*, 9 (1): 6-8.

[13] Lal, O.P. 1998. Notes summer school on "*Advance Technologies in Important Vegetable Crops, including Cole Crops*". May 4-24, I.A.R.I. New Delhi, pp. 63-66.

[14] Mohan, N. J.; Krishnaiah, K.; Kumar, N. K. K. 1981 Chemical control of mustard aphid, *Lipaphis erysimi* (Kalt). And leaf webber, *Crocidolomia binotalis* Zell. on cabbage, *Pesticides* 1981, 15 (2) 29-32.

[15] Meena, S.C. and Singh, V. 2012. Sesonal incidence of *Plutella xylostella (*L.) on cabbage in arid region of Rajasthan. *Annals of Plant Protection Sciences,* 20 (3): 326-328.

[16] Prasad, S.K. 1963. Quantitative estimation of damage to cruciferous crops caused by cabbage worm, cabbage lopper, diamondback moth and cabbage aphid. *Indian Journal of Entomology*, 25 (3: 242-259.

[17] Rao, S.R.K. and Lal, O.P. 2005. Seasonal incidence of mustard aphid, *Lipaphis erysimi* (Kalt) and diamondback moth, *Plutela xylostella* (L.) on cabbage. *Journal of Insect Science*, 18 (2): 106-110.

[18] Sachan, J.N. and Srivastava, B.P. 1972. Studies of the seasonal incidence of insect pests of cabbage. *Indian Journal of Entomology*, 34 (2): 123-129.

[19] Shukla, A. and Kumar, A. 2003. Seasonal activity of larval parasitoid, *Cotesia plutellae* (Kurdj.) in cabbage eco*system*. *Journal of Entomological Research*, 27 (3): 181-184.

[20] Sannaveerappanavar, V.T. Kamla, N.V. Shankaramurthy, M. and Chandrashekhara, K. 2003. Field evaluation of insecticides against diamondback moth on cabbage. National Symposium on frontier areas of Entomological Research 5-7 November, 2003, New Delhi.

[21] Sharma, S.K. 2004. Eco-safe management of major insect pests of cabbage *Brassica oleracea* var. *capitata* Linn. Ph.D Thesis, Submitted to Rajasthan Agricultural University, Bikaner.

[22] Shukla, A. and Kumar, A. 2004. Seasonal incidence of diamondback moth, *Plutella xylostella* (Linn.) in relation to abiotic factors in cabbage. *Plant Protection Bulletin*, 1: 37-38.

[23] Taleker, N. S. and Shelton, A.M. 1993. Biology, Ecology and Management of the Diamondback Moth. *Annual review of entomology* 38 (1) 275-301.

[24] Shukla, A. and Kumar, A. 2006. Seasonal activity of *Tetrastichus sokolowski* a pupal parasitoid of *Plutella xylostella* (Linn.) in cabbage ecosystem. *Journal of Entomological Research,* 30 (2): 155-157.

Study the Effect of Integrated Nutrient Management on Growth and Yield of Cauliflower

Alka Choudhary[1*]; Dr. Mahesh Kumar[2]; Mukesh Jakhar[3]; Ram Narayan Bhateshwar[4]

[*1]M.Sc. (Ag.) Horticulture Maharaja Agrasen Himalayan Garhwal University Shiv Nagar, Dhaid Gaon, Block pokhra, District Pauri Garhwal, Uttarakhand Pin Code – 246169

[2]Assistant Professor Maharaja Agrasen Himalayan Garhwal University Shiv Nagar, Dhaid Gaon, Block pokhra, District Pauri Garhwal, Uttarakhand Pin Code – 246169

[3]M.Sc. (Ag.) student, Department of Entomology, Raja Balwant Singh college of Agriculture, Bichpuri, UP.

[4]M.Sc. (Ag.) student, Department of Plant Breeding, Raja Balwant Singh college of Agriculture, Bichpuri, UP.

*Corresponding Author

Received:- 16 April 2025/ Revised:- 24 April 2025/ Accepted:- 28 April 2025/ Published: 30-04-2025

Abstract— *A field experiment entitled "Effect of Integrated Nutrient Management on Growth and Yield of Cauliflower (Brassica oleracea var. Botrytis L.)" was conducted at Research Farm, Himalayan Garhwal University, Uttarakhand during Rabi season of 2020-21. The experiment was laid out in factorial randomized block design with three replications and consisting four fertility levels (Control, 50% RDF, 75% RDF and 125% RDF) and three treatments of organic manure (control, FYM @ 20 t/ha + Azospirillum and vermicompost @ 7.5 t/ha + Azospirillum).*

Results showed that application of 100% RDF significantly increased the plant height, number of leaves per plant, plant spread, days taken to curd maturity, biological yield, curd diameter, fresh weight of curd, curd yield, nitrogen, phosphorus and potassium content, net returns and B: C ratio of cauliflower which was superior as compared to control and 50% RDF.

Keywords— Integrated, Nutrient Management, manure, experiment.

I. INTRODUCTION

Cauliflower (*Brassica oleracea var. botrytis* L.) is one of the most popular cruciferous vegetables among the cole crops grown in India. It is cultivated for its attractive curd which is used for making vegetable curry, soup and pickles. Cauliflower predominant due to its attractive appearance, good taste, source of minerals, protein and vitamins and has high yielding capacity. Hundred-gram edible portion of cauliflower has high quality protein (2.6g), moisture (90.8 g), fat (0.4 g), carbohydrates (4.0 g), calcium (33.0 mg), phosphorous (57.0 mg), iron (1.5 mg), thiamine (0.04 mg), riboflavin (0.10 mg), vitamin C (56.0 mg) and energy (30 kcal). In fact, cauliflower contains calcium nearly ten times as much as meat and four times as much as eggs. India is the largest producer of cauliflower in the world.

There has been substantial increase both in the production and productivity of the vegetables with the adoption of high yielding varieties and improved production technologies. Cauliflower is a heavy feeder of nutrients they're by the use of chemical fertilizers is increasing day by day and the indiscriminate use of chemical fertilizers has simultaneously resulted in many problems like degradation of soil productivity, environment pollution, depletion of non- renewable source of energy etc. Moreover, chemical fertilizers are becoming costlier input in agriculture. Thus, integrated nutrient management refers to the "maintenance of soil fertility and plant nutrient supply at an optimum level for sustaining the productivity through optimization of the benefits from all possible sources of organic, inorganic and biological compounds in an integrated approach."

Nitrogen plays a key role in nutrition of the plants. As a matter of fact, the plant life would not be possible without this element. Adequate amount of nitrogen is also required to obtain good yield in vegetable crops. Phosphorous and potassium are considered as major nutrients in crops and they are involved in all the metabolic process in the plant and there is considerable evidence to show that, these element plays an important role in photosynthesis and helps in building up of carbohydrate in the plant. The production of dry matter is further affected by the effect of potassium on rate of respiration.

Organic manures and biofertilizers are the important components of integrated nutrient management as supply the trace amounts of micronutrients which are generally not supplied by the farmers to their vegetable crops. Vermicompost is the product of ingested biomass by earthworm after undergoing physical, chemical and microbial transformations and available in the form of cast.

II. MATERIAL AND METHODS

2.1 Characteristics of the experimental field:

The soil of the field selected for the present study was sandy loam having uniform fertility. Representative soil samples were taken before transplanting of the crop from five different places of the experimental field at depth of 20 cm. The soil samples were mixed thoroughly and three uniform samples were analyzed for assessing the initial status of the soil. The physic-chemical characteristics of the soil.

TABLE 1
INITIAL PHYSIO-CHEMICAL CHARACTERISTICS OF THE EXPERIMENTAL SOIL

Soil properties	Value (0-15 cm)	Methods of analysis with reference
A. Mechanical Composition		
Sand (%)	72	Hydrometer method (Bouyoucos, 1962)
Silt (%)	19	
Clay (%)	9	
Texture	Loamy sand	Triangular method (Brady, 1983)
B. Physical properties		
Bulk density (Mg m^{-3})	1.53	Method No. 38, USDA Hand Book No. 60 (Richards, 1972)
Particle density (Mg m^{-3})	2.52	Method No. 39, USDA Hand Book No. 60 (Richards, 1972)
Porosity (%)	39.28	Method No. 40, USDA Handbook No. 60 (Richards, 1972)
C. Chemical properties		
Organic carbon (%)	0.42	Walkley and Black's rapid titration method (Walkley and Black, 1934)
Available N (kg ha^{-1})	134.66	Alkaline KMnO4 method (Subbiah and Asija, 1956)
Available P2O5 (kg ha^{-1})	21.08	Olsen's method (Olsen *et al.*, 1954)
Available K2O (kg ha^{-1})	233.23	Flame photometric Method (Jackson, 1973)
EC (dsm^{-1})	0.27	Method No. 4 USDA Handbook No.60 (Richards, 1972)
Soil pH (1:2 soil water suspension at 25^0C)	7.6	Method No. 21 b, USDA Handbook No. 60 (Richards, 1972)

III. RESULT AND DISCUSSION

3.1 Effect of integrated nutrient management on growth attributes:

3.1.1 Plant height (cm):

- **Effect of fertility levels:** The data presented indicated that plant height of cauliflower was affected significantly by different fertility levels at harvest stage. Application of 100% RDF being remained at par with application of 75% RDF, recorded significantly highest plant height at harvest as compared to control and 50% RDF. The increase in plant height due to application 100% RDF was 25.88 and per cent at harvest over control and 50% RDF, respectively.

- **Effect of organic manure:** The data presented revealed that the plant height of cauliflower was affected significantly by application of organic manure at harvest. Maximum plant height of cauliflower was recorded with the application of vermicompost @ 7.5 t/ha + *Azospirillum* which was significantly higher than control and FYM @ 20 t/ha + *Azospirillum*. The increase in plant height due to application of vermicompost @ 7.5 t/ha + *Azospirillum* was 18.47 and 7.82 per cent at harvest over control and FYM @ 20 t/ha + *Azospirillum*, respectively.

TABLE 2
EFFECT OF INTEGRATED NUTRIENT MANAGEMENT ON PLANT HEIGHT OF CAULIFLOWER

Treatments	Plant height (cm) at harvest
Fertility levels	
Control	43.04
50 % of RDF	48.66
75 % of RDF	53.22
100 % of RDF	54.17
SEm ±	1.39
CD (P=0.05)	4.07
Organic manure	
Control	45.47
FYM @ 20 t/ha + *Azospirillum*	49.97
Vermicompost @ 7.5 t/ha + *Azospirillum*	53.88
SEm ±	1.2
CD (P=0.05)	3.53

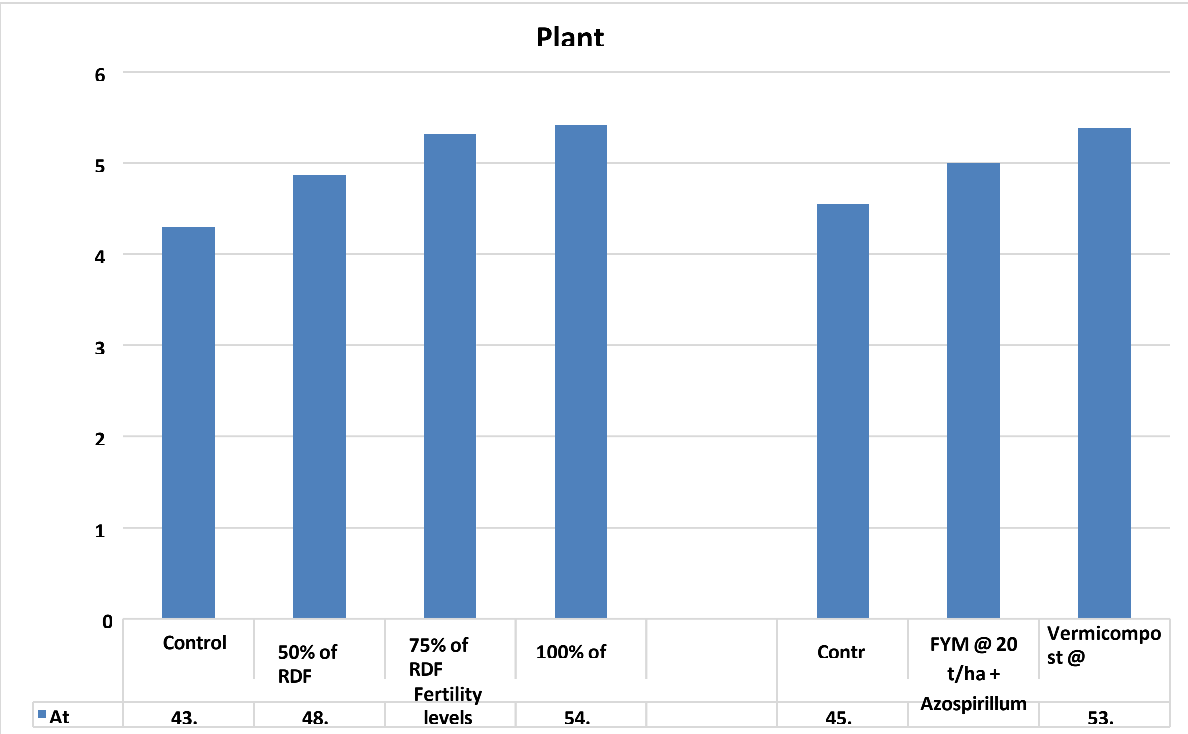


FIGURE 1

3.1.2 Number of leaves per plant:

- **Effect of fertility levels:** A close perusal of revealed that the application of 100% RDF recorded significantly highest number of leaves per plant in cauliflower at harvest as compared to control and 50% RDF. The increase in number of leaves per plant due to application of 100% RDF was 27.40 and 11.38 per cent over control and FYM @ 20 t/ha + *Azospirillum*, respectively.
- **Effect of organic manure:** A critical screening of revealed that the significantly highest number of leaves per plant in cauliflower at harvest was recorded with the application of vermicompost @ 7.5 t/ha + *Azospirillum* which was superior to control and FYM @ 20 t/ha + *Azospirillum*. The enhancement in number of leaves per plant in cauliflower

due to application of vermicompost @ 7.5 t/ha + *Azospirillum* was 20.93 and 8.03 per cent, respectively over control and FYM @ 20 t/ha + *Azospirillum*.

3.2 Plant spread (cm2):

3.2.1 Effect of fertility levels:

The data given showed that the application of different fertility levels significantly influenced the plant spread of cauliflower at harvest. Application of 100% RDF recorded significantly maximum plant spread of cauliflower at harvest as compared to control and 50% RDF but it was found at par with 75% RDF. Plant spread of cauliflower increased due to application 100% RDF by 28.47 and 11.31 per cent over control and 50% RDF, respectively at harvest.

3.2.2 Effect of organic manure:

It is evident from the plant spread of cauliflower was affected significantly by application of organic manure. Maximum plant spread of cauliflower was recorded with the application of vermicompost @ 7.5 t/ha + Azospirillum which was significantly higher than control and FY2.1M @ 20 t/ha + Azospirillum. The increase in plant spread of cauliflower at harvest due to application of vermicompost @ 7.5 t/ha + Azospirillum was 27.37 and 8.60 per cent over control and FYM @ 20 t/ha + Azospirillum, respectively.

3.3 Days taken to curd maturity:

- **Effect of fertility levels:** The experimental findings presented revealed that the application of different fertility levels brings significant variation in days taken to curd maturity of cauliflower. The maximum and minimum days taken to curd maturity of cauliflower was recorded in control and application of 100% RDF treatment.
- **Effect of organic manure:** A perusal of data presented indicated that the days taken to curd maturity of cauliflower was affected significantly due to application of organic manures. The maximum and minimum days taken to curd maturity of cauliflower was recorded in control and application vermicompost @ 7.5 t/ha + *Azospirillum* treatment.

The findings of the present investigation showed that different fertility levels significantly enhanced the vegetative growth of cauliflower. The maximum value of growth parameters was recorded with 100% of RDF which was significantly superior over control and 50% RDF. The increase in growth parameters under application of 100% RDF may be due to better start and early seedling vigor under the optimum levels of inorganic sources of nutrient which indicates proper nutrients utilization during early growth stages of the crop. Increased nutrient status of the soil and more availability of the nutrients at initial stage under optimum moisture status in the soil provide favorable conditions for effective growth and development of the crop. This might have resulted in increase in vegetative growth mainly by elongation of cells and partly cell division. The adequate supply of the three major nutrients *viz.* NPK is expected to regulate plant physiological functions and morphological responses favorably because nitrogen is considered one of the major nutrients required for proper growth and development of plant. Nitrogen is an important constituent of protoplasm and its favourable effect on chlorophyll content of leaves might have increased the synthesis of carbohydrates, amino acids etc., from which the phyto-hormones such as auxins, gibberellins and cytokinins have been synthesized resulting in increased plant height. Whereas, the beneficial effect of phosphorus in early stage of growth may be due to early stimulation of root system, efficient translocation of compounds in phosphorus fed plants, leading to enhanced absorption and utilization of nitrogen and other nutrients. Potassium helps in the protein synthesis, chlorophyll formation and increasing resistance against stress which might have improved growth and development of the plant. The faster availability of nutrients from adequate supply of inorganic fertilizers through-out the cropping period enhances the nutrient requirement of the crop and production of greater number of photo-synthetically active leaves which might have led to higher production of carbohydrates and phyto-hormones which resulted in increased growth attributes of cauliflower. The results are in close agreement with the finding of Singh et al. (2018) and Singh et al. (2020).

IV. CONCLUSION

Keeping in view the objectives to undertake the study and the results obtained after conducting the experiment for one year, it has been concluded that application of different integrated nutrient management treatments significantly enhanced the growth parameters, yield attributes, yields, nutrient content and economics of cauliflower. Application of 100% RDF gave significantly higher growth parameters, yield attributes, yield, and nutrient content and net returns of cauliflower over control and application of 50% RDF. The application of vermicompost @ 7.5 t/ha + Azospirillum gave significantly highest growth parameters, yield attributes, yield, nutrient content and net returns of cauliflower as compared to control and application of FYM @ 20 t/ha +

Azospirillum. However, these results are only indicative and required further experimentation to arrive some more consistent and final conclusion.

REFERENCES

[1] Asokan, R, Sukhada, M. and Lalitha, A. (2000) Biofertilizers and biopesticides for horticultural crops, *Indian Horticulture* **2**: 44-52

[2] Bahadur, A. Singh, J. Upadhyay, A. K. and Singh, K. P. (2003) Effect of organic manures and biofertilizers on growth, yield and quality attributes of broccoli (*Brassica oleracea* var. *Italica plenck*). *Vegetable Science*, 30(2): 192-194.

[3] Edwards, C. A. and Arancon, N. Q. (2004) Interactions among organic matter, earthworms and microorganisms in promoting plant growth. Soil Organic Matter in Sustainable Agriculture, pp. 327-376.

[4] Kanwar, K. Paliyal, S. S. and Nandal, T. R. (2002) Integrated nutrient management in Cauliflower (Pusa Snowball K-1), Research on Crops 3(3): 579-589.

[5] Kashyap, L. Reddy, C. V. and Tiwari, A. (2017) Effect of integrated nutrient management practices effect on carbon sequestration, carbon stock, plant growth parameters and economics of cauliflower, International Journal of Current Microbiology and Applied Sciences, 6(7): 1407-1415.

[6] Khan, N. Singh, S. K. Srivastava, J. P. and Siddiqui, M. Z. (2010) Effect of biofertilizers on production potential and economic feasibility of Cauliflower (Brassica oleracea var. botrytis L.), Progressive Agriculture 10(2): 371-373

[7] Singh, V. N. and Singh, S. S. (2018) Effect of inorganic and biofertilizers on production of cauliflower (*Brassica oleracea* var. *botrytis* L.), *Vegetable Science* **32**(2): 146-149

[8] Singh, A., Kumar, A., Yadav, S. and Singh, S., 2020. Effect of integrated nutrient management on growth and yield of cabbage (Brassica oleracea var. capitata L.). *IJCS*, **8**(3), pp.1196-1200.

Find out the Effect of Organic Manure Integrated Nutrient Management on Quality of Cauliflower

Alka Choudhary[1*]; Dr. Mahesh Kumar[2]; Mukesh Jakhar[3]; Ram Narayan Bhateshwar[4]

[*1]M.Sc. (Ag.) Horticulture Maharaja Agrasen Himalayan Garhwal University Shiv Nagar, Dhaid Gaon, Block pokhra, District Pauri Garhwal, Uttarakhand Pin Code – 246169

[2]Assistant Professor Maharaja Agrasen Himalayan Garhwal University Shiv Nagar, Dhaid Gaon, Block pokhra, District Pauri Garhwal, Uttarakhand Pin Code – 246169

[3]M.Sc. (Ag.) student, Department of Entomology, Raja Balwant Singh college of Agriculture, Bichpuri, UP.

[4]M.Sc. (Ag.) student, Department of Plant Breeding, Raja Balwant Singh college of Agriculture, Bichpuri, UP.

*Corresponding Author

Received:- 16 April 2025/ Revised:- 25 April 2025/ Accepted:- 28 April 2025/ Published: 30-04-2025

Abstract— *The experiment was laid out in factorial randomized block design with three replications and consisting four fertility levels (Control, 50% RDF, 75% RDF and 125% RDF) and three treatments of organic manure (control, FYM @ 20 t/ha + Azospirillum and vermicompost @ 7.5 t/ha + Azospirillum).*

Results showed that application of 100% RDF significantly increased the plant height, number of leaves per plant, plant spread, days taken to curd maturity, biological yield, curd diameter, fresh weight of curd, curd yield, nitrogen, phosphorus and potassium content, net returns and B: C ratio of cauliflower which was superior as compared to control and 50% RDF.

Keywords— Replications, Maturity, Biological, Significantly.

I. INTRODUCTION

There has been substantial increase both in the production and productivity of the vegetables with the adoption of high yielding varieties and improved production technologies. Cauliflower is a heavy feeder of nutrients they're by the use of chemical fertilizers is increasing day by day and the indiscriminate use of chemical fertilizers has simultaneously resulted in many problems like degradation of soil productivity, environment pollution, depletion of non- renewable source of energy etc. Moreover, chemical fertilizers are becoming costlier input in agriculture. Thus, integrated nutrient management refers to the "maintenance of soil fertility and plant nutrient supply at an optimum level for sustaining the productivity through optimization of the benefits from all possible sources of organic, inorganic and biological compounds in an integrated approach."

Nitrogen plays a key role in nutrition of the plants. As a matter of fact, the plant life would not be possible without this element. Adequate amount of nitrogen is also required to obtain good yield in vegetable crops. Phosphorous and potassium are considered as major nutrients in crops and they are involved in all the metabolic process in the plant and there is considerable evidence to show that, these element plays an important role in photosynthesis and helps in building up of carbohydrate in the plant. The production of dry matter is further affected by the effect of potassium on rate of respiration.

Organic manures and biofertilizers are the important components of integrated nutrient management as supply the trace amounts of micronutrients which are generally not supplied by the farmers to their vegetable crops. Vermicompost is the product of ingested biomass by earthworm after undergoing physical, chemical and microbial transformations and available in the form of cast. Earthworm reduces the C: N ratio, increases humic acid, cation exchange capacity and water-soluble carbohydrates.

II. MATERIAL AND METHOD

2.1 Experimental details (Design and layout):

The present experiment consisting of 12 treatment combinations was laid out in Factorial Randomized Block Design. Treatments details along with their symbols and other details of experiment are presented in table 1.1 and table 1.2.

TABLE 1
DETAILS OF THE EXPERIMENT ARE AS FOLLOWS

1.	Season	:	*Rabi*, 2020-21
2.	Experimental design	:	Factorial Randomized Block Design
3.	Crop	:	Cauliflower
4.	Total number of treatments	:	4 x 3
5.	No. of replications	:	3
6.	Total number of plots	:	12 x 3 = 36
7.	Plot size	:	2.40 m × 3.15 m = 7.56 m^2
8.	Spacing	:	60 cm x 45 cm

TABLE 2
CHRONOLOGICAL RECORD OF RAISING CABBAGE CROP

S. No.	Operations	Date
1.	Seed sowing in nursery	09.10.2020
2.	Ploughing and planking of field	16.11.2020
3.	Preparation of beds	17.11.2020
4.	Transplanting of seedling	19.11.2020
5.	Irrigation	At an interval of 7-10 days
6.	Cultural operations	As and when required
7.	Harvesting	29.01.2021 to 11.02.2021

2.2 Statistical analysis:

To test the significance of variation in data obtained from various growth, yield and quality characters, the technique of analysis of variance was adopted as suggested by Panse and Sukhatme (1967), for randomized block design. Significance of difference in the treatment effect was tested through 'F' test at 5 per cent level of significance and CD (critical difference) was calculated. The analysis of variance for all the data discussed is given in the appendix-XII.

III. RESULT AND DISCUSSION

3.1 Effect of integrated nutrient management on yield attributes and yield:

Biological yield (q/ha)

- **Effect of fertility levels:** The data revealed that different fertility levels were significantly affected the biological yield of cauliflower. Highest biological yield of cauliflower was recorded with the application of 100% RDF as compared to control and 50% RDF but found at par with 75% RDF. Biological yield of cauliflower increased due to application 100% RDF by 27.88 per cent over control and 11.89 per cent over 50% RDF.

- **Effect of organic manure:** A critical screening of data revealed that application of organic manures had significant effect on biological yield of cauliflower. The significantly highest biological yield of cauliflower was recorded with the application of vermicompost @ 7.5 t/ha + *Azospirillum* which was superior to control and FYM @ 20 t/ha + *Azospirillum*. The enhancement in biological yield of cauliflower due to application vermicompost @ 7.5 t/ha + *Azospirillum* was 27.52 and 10.75 per cent as compared to control and FYM @ 20 t/ha +*Azospirillum*, respectively.

TABLE 3
EFFECT OF INTEGRATED NUTRIENT MANAGEMENT ON DAYS TAKEN TO CURD MATURITY OF CAULIFLOWER:

Treatments	Days taken to curd maturity
Fertility levels	
Control	98.41
50 % of RDF	84.55
75 % of RDF	74.06
100 % of RDF	72.30
SEm ±	3.32
CD (P=0.05)	9.74
Organic manure	
Control	95.04
FYM @ 20 t/ha + *Azospirillum*	81.61
Vermicompost @ 7.5 t/ha + *Azospirillum*	70.34
SEm ±	2.87
CD (P=0.05)	8.43

TABLE 4
EFFECT OF INTEGRATED NUTRIENT MANAGEMENT ON BIOLOGICAL YIELD OF CAULIFLOWER

Treatments	Biological yield (qha)
Fertility levels	
Control	367
50 % of RDF	420
75 % of RDF	467
100 % of RDF	469
SEm ±	14
CD (P=0.05)	41
Organic manure	
Control	377
FYM @ 20 t/ha + *Azospirillum*	434
Vermicompost @ 7.5 t/ha + *Azospirillum*	481
SEm ±	12
CD (P=0.05)	35

Curd diameter (cm^2)

Effect of fertility levels:

An investigation of data revealed that curd diameter of cauliflower increased significantly with increasing fertility levels. Significantly maximum curd diameter was obtained with the application of 100% RDF which was significantly higher over control and 50% RDF and remained at par with application of 75% RDF. Curd diameter of cauliflower increased due to application 100% RDF by 30.64 and 13.04 per cent over control and 50% RDF.

Effect of organic manure:

A critical examination of data indicated that application of vermicompost @ 7.5 t/ha + *Azospirillum* gave significantly maximum curd diameter of cauliflower over control and FYM @ 20 t/ha + *Azospirillum*. The magnitude of increase in curd diameter of cauliflower due to application of vermicompost @ 7.5 t/ha + *Azospirillum* was 31.52 and 11.69 per cent as compared to control and 30 t /ha FYM, respectively.

Fresh weight of curd (kg)

Effect of fertility levels:

A critical examination of data indicated that different fertility levels had significant influence on fresh weight of curd of cauliflower. Among different treatments, 100% RDF, being at par with 75% RDF and gave significantly maximum fresh weight of curd of cauliflower over control and 50% RDF. The magnitude of increase in curd weight per plant of cauliflower due to application 100% RDF was 35.11 and 12.66 per cent, respectively over control and50% RDF.

Effect of organic manure:

An investigation of data revealed that fresh weight of curd of cauliflower increased significantly with application of organic manure. Significantly maximum fresh weight of curd of cauliflower was obtained with the application of vermicompost @ 7.5 t/ha + *Azospirillum* which was significantly higher than control and FYM @ 20 t/ha + *Azospirillum*. Curd weight per plant of cauliflower increased by 28.93 and 11.51 per cent over control and FYM @ 20 t/ha + *Azospirillum*, respectively.

TABLE 5
EFFECT OF INTEGRATED NUTRIENT MANAGEMENT ON YIELD ATTRIBUTES OF CAULIFLOWER

Treatments	Curd diameter (cm^2)	Fresh weight of curd (g)
Fertility levels		
Control	15.96	0.621
50 % of RDF	18.44	0.744
75 % of RDF	20.65	0.830
100 % of RDF	20.84	0.839
SEm ±	0.57	0.027
CD (P=0.05)	1.67	0.079
Organic manure		
Control	16.30	0.660
FYM @ 20 t/ha + *Azospirillum*	19.19	0.764
Vermicompost @ 7.5 t/ha + *Azospirillum*	21.43	0.851
SEm ±	0.49	0.023
CD (P=0.05)	1.44	0.069

Curd yield

Effect of fertility levels:

Further reference of data given in revealed that curd yield of cauliflower was significantly increased due to the different fertility levels. The highest curd yield of cauliflower was recorded under the treatment of 100% RDF which was significantly higher over control and 50% RDF and remained at par with 50% RDF. The increase in curd yield of cauliflower due to 100% RDF was 34.06 and 13.00 per cent over control and 50% RDF.

Effect of organic manure:

It is evident from the data in that the significantly highest curd yield of cauliflower was recorded with application of vermicompost @ 7.5 t/ha + *Azospirillum* as compared to control and FYM @ 20 t/ha + *Azospirillum*. The increase in curd yield due to application of vermicompost @ 7.5 t/ha + *Azospirillum* in terms of per cent was 31.77 and 11.28 per cent, respectively over control and FYM @ 20 t/ha + *Azospirillum*.

Effect on yield attributes and yield

In the present investigation, there was significant increase in yield attributes and yields of cauliflower with different fertility levels. The maximum mean values of yield attributes and yield of cauliflower obtained with the application of 100% of RDF which was significantly superior to control and 50% of RDF.

The beneficial response of inorganic sources of nutrient on yield attributes and yield of cauliflower might be due to the availability of sufficient amount of plant nutrients throughout the growth period of crop resulting in better uptake of nutrients, plant vigor and improved yield. The increase in yield attributes may be explained due to increase in number of leaves under high fertility levels. With the application of higher levels of fertility, the tissue differentiations from the somatic to reproductive, meristematic activity and the development of floral primordial might have been enhanced causing greater production of flowers. Higher fertility level induced greater translocation of photosynthates from leaves via stem to curd and these resulted in higher yield attributes. The increase in yield may also be due to better uptake of nutrients from the soil which might have contributed to increased dry matter accumulation and number of leaves per plant ultimately enhanced curd yield of cauliflower. Similar finding was reported by Khare and Singh (2008), Sarkar *et al.* (2010), Yadav *et al.* (2012), Chaudhary *et al.* (2015) and Singh *et al.* (2018).

IV. CONCLUSION

Effect of organic manure

The maximum plant height of cauliflower was recorded with the application of vermicompost @ 7.5 t/ha + *Azospirillum* which was significantly higher than control and FYM @ 20 t/ha + *Azospirillum*.

The significantly highest number of leaves per plant in cauliflower was recorded with the application of vermicompost @ 7.5 t/ha + *Azospirillum* which was superior to control and FYM @ 20 t/ha + *Azospirillum*.

Keeping in view the objectives to undertake the study and the results obtained after conducting the experiment for one year, it has been concluded that application of different integrated nutrient management treatments significantly enhanced the growth parameters, yield attributes, yields, nutrient content and economics of cauliflower. Application of 100% RDF gave significantly higher growth parameters, yield attributes, yield, nutrient content and net returns of cauliflower over control and application of 50% RDF.

REFERENCES

[1] Bahadur, A. Singh, J. Upadhyay, A. K. and Singh, K. P. (2003) Effect of organic manures and biofertilizers on growth, yield and quality attributes of broccoli (*Brassica oleracea* var. *Italica plenck*). *Vegetable Science*, 30(2): 192-194.

[2] Devi, M. Upadhyay, G.P. Garima and Spehia, R. S. (2017) Biological properties of soil and nutrient uptake in cauliflower (*Brassica oleracea* var botrytis L.) as influenced by integrated nutrient management, *Journal of Pharmacognosy and Phytochemistry*, **6**(3): 325-328.

[3] Edwards, C. A. and Arancon, N. Q. (2004) Interactions among organic matter, earthworms and microorganisms in promoting plant growth. Soil Organic Matter in Sustainable Agriculture, pp. 327-376

[4] Kumar, V. and Devi, S. (2016) Effect of Bio-fertilizers and Inorganic Amendments on Mineral Composition and Quality of *Brassica oleracea Asian Journal of Advanced and Basic Science,* **4**(2): 20-26

[5] Kumar, V. Kumar, V. Tyagi, A. K. Singh, B. and Kumar, N. (2010) Effect of vermicompost and VAM inoculation on growth and yield of cauliflower (*Brassica oleracea* L. var. *botrytis*) *Progressive Agriculture,* **10:** 197-199.

[6] Narayanamma, M. Chiranjeevi, Ch. and Ahmed, S. R. (2004) Integrated nutrient management in cauliflower *(Brassica oleracea* var. *botrytis* L), *Proceedings of the First Indian Horticulture Congress*, New Delhi, November, **6**(9): 247.

Sustainable Horticulture Practices: An Environmentally Friendly Approach

Ronak Kuri[1*]; Santosh Kumar Jakhar[2]; Naresh Kumar[3]; Santosh Choudhary[4]; Mahesh Kumar Poonia[5]

[*1]Ph.D. scholar Department of Horticulture, Agriculture University, Jodhpur, Rajasthan 342304, India.
[2]Master's Scholar, Department of Animal Science, Palli Siksha Bhavana (Institute of Agriculture) Visva-Bharati Sriniketan, West Bengal, India
[3]Ph.D. scholar Department of Agronomy, Agriculture University, Jodhpur, Rajasthan 342304, India.
[4]Assistant Professor, Department of Horticulture, Agriculture University, Jodhpur, Rajasthan 342304, India.
[5]Professor, Department of Horticulture, Agriculture University, Jodhpur, Rajasthan 342304, India.
*Corresponding Author

Received:- 18 April 2025/ Revised:- 24 April 2025/ Accepted:- 29 April 2025/ Published: 05-05-2025

Abstract— *This summary paper provides a general overview of sustainable gardening methods, highlighting many environmentally friendly technologies used in the industry. Horticulture is extremely important to conserving food, green cities and biological diversity. However, traditional garden tree methods often have negative environmental impacts, such as soil erosion, water pollution, and greenhouse gas emissions. The introduction of sustainable and ecologically friendly practices in gardening has become increasingly important in recent years. In order to reduce environmental impacts, increase production and promote long-term sustainability, this review examines and evaluates the effectiveness of various strategies. This study analyzes many critical issues, including organic farming, integrated pest control, water protection, soil health treatment, and improving biodiversity. Research shows that eco-friendly garden practices can also lead to lower ecosystem input costs and better benefits. However, there are also difficulties and potential information regarding the widespread use of these techniques. The analysis concludes with suggestions for additional research and useful findings on promoting sustainable horticultural practices.*

Keywords— Sustainable horticulture, ecologically friendly, organic farming, integrated pest management, water conservation, biodiversity.

I. INTRODUCTION

This summary paper provides a general overview of sustainable gardening methods and illustrates many environmentally friendly technologies used in the industry. Horticulture is extremely important for the conservation of food, green cities and biological diversity. However, traditional garden tree methods are often negatively affected to the environment, such as soil erosion, water pollution and greenhouse gas emissions. The introduction of sustainable and ecologically friendly practices in gardening has become increasingly important in recent years. To reduce environmental impacts, increase production and promote long-term sustainability, this review examines and evaluates the effectiveness of various strategies. This study analyzes many critical issues, including organic farming, integrated pest control, water protection, soil treatment, and improved biodiversity. Research shows that eco-friendly garden practices can also lead to lower ecosystem costs and better benefits. However, there are also difficulties and potential information regarding the widespread use of these techniques. The analysis concludes with suggestions for additional research and useful knowledge to promote sustainable gardening practices.

II. SUSTAINABLE HORTICULTURE PRACTICES

These are following practices apply in sustainable horticulture.

2.1 Organic Farming in Horticulture:

Cultivation of fruits, vegetables, flowers and other garden plants using other natural methods and ingredients is highlighted in organic farming, an eco-friendly style of gardening. This method avoids artificial pesticides, fertilizers, and genetically modified organisms (GVOs) and supports sustainable agricultural systems suitable for the environment and human health. In this section you can find an overview of organic garden building areas and agriculture in discussion. Organic farming prioritizes soil biological diversity and health conservation, reducing adverse environmental impacts. Organic farmers are B. They use a variety of methods, including plant rotation, composting, green manure, and using insects that help to control pests rather than relying on synthetic pesticides. These methods contribute to increased microbial activity, reduced soil erosion, improved water and nutrient retention, and improved soil fertility (Reganold et al., 2010) [8]. This is one of the main benefits of organic farming in horticulture by reducing the use of synthetic pesticides and fertilizers, maintaining ecosystems, and reducing soil and water pollution. According to research (Zaller et al., 2019) [1], bioagriculture practices can dramatically reduce pesticide residues in plants and surrounding areas. Compared to traditional reared products, organic fruits and vegetables were found to have higher concentrations of some essential nutrients and antioxidants (Baranski et al., 2014) [5]. Through the supply of habitat for economic creatures such as pollinators and natural opponents of pests, biological agriculture helps the presence of biological diversity in gardening aids. By enabling the presence of different plant species, it strengthens, compensates for, and corrects ecosystems. According to research (Bommarco et al., 2013; Hole et al., 2005) [6, 7], organic farming has a positive effect on birds, favorable insects and pollinators. This highlights the potential for biological horticulture to support animal welfare.

2.2 Integrated Pest Management (IPM):

Integrated pest management (IPM) is an important horticultural method for combining many tactics to efficiently control pests while simultaneously reducing the use of chemical pesticides and adverse environmental impacts. IPM practices combine biological, cultural, physical and chemical management techniques to maintain pest populations at harmful levels, while simultaneously promoting ecological balance and reducing human health risks. In this section, you will find a summary of the IPM techniques and arguments used in horticulture. The use of natural enemies, including predators, parasites and viruses, for the treatment of pest populations, is known as biological controls and is one of the main principles of IPM in horticulture. More sustainable self-regulation systems for pest control can be developed by releasing or maintaining biological control measures by altering the availability of habitats, selective plants, and alternative food sources (Gontijo et al., 2018) [4]. Cultural practices play an important role in IPM by promoting adverse pest conditions and increasing health and resistance to plants. Harvest, use of resistant types, good hygiene, and timing of planting are some cultural practices that break the pest lifecycle and reduce pest load. In IPM, physical exclusion or removal of pests from the harvest environment is the goal of a physical control approach. Examples include using pest control machines and using barriers, falls, networks and traps. These techniques can be extremely efficient, especially in combination with other IPM tactics. Chemical control is the final line of defense in IPM and is only used when this is absolutely necessary. Selected target pesticide treatments are administered as needed based on pest monitoring and thresholds. IPM promotes the use of pesticides because it has little negative effects on the environment and non-target creatures and therefore has little risk. IPM techniques have many benefits for horticultural purposes. They reduce the need for pesticides, delay the development of pesticide resistance in pesticides, protect natural predators and allies, and reduce unintended creatures and the environment. Research shows that IPM has successfully performed pesticides in plants, promoting biodiversity, and increasing general harvests (Gontijo et al., 2018; Parrella et al., 2009) [4, 9].

2.3 Water Conservation in Horticulture:

Maintaining water is an important part of sustainable garden practices as water shortages and effective water resource management become more important. In this section you can find a summary of the water conservation techniques and discussions used in horticulture. Drip irrigation is a very effective way to protect water in horticulture. In contrast to traditional irrigation techniques, water directly into the plant's root zones minimizes evaporation and drainage. According to Chaves et al. (2019) [3] Drip irrigation system can save up to 50% water, while maintaining ideal herbal hydration. In addition to reducing weed growth and fungal infections, fungal infections associated with too much moisture in crafts also inhibit accurate control of watering. Precision irrigation is another strategy of water conservation used in the latest technology depending on the individual requirements of plants from top technology. To plan irrigation more effectively and avoid excessive gradation, weather information, soil moisture sensors and computer-controlled systems. Precision irrigation maximizes the efficiency of water consumption and minimizes water waste by specifying only the locations and locations needed (Chaves et al., 2019) [3]. Recycled water is becoming more and more popular in horticultural form than sustainable water supply. It is possible to convert treated wastewater, gray water, or accumulation accumulation for irrigation. Water recycling is an important resource for plant nutrition as it reduces nutrient contamination in wastewater and preserves freshwater resources. Intensive monitoring and correct treatment are required to ensure the safety and purity of recycled water for horticultural applications (Chaves et al., 2019) [3]. Covering the floor with organic or synthetic materials is an effective mulching practice for obtaining water. Mulch preserves soil levels, inhibits weed development and reduces soil evaporation. Although they break down over time, organic mulch such as straws, wooden chips, and compost can help improve soil structure and fertility (Borrelli et al., 2019) [2]. Mulch also helps regulate soil temperature by reducing excessive variation, contaminating the system and increasing water requirements. Another way to keep water in gardening is to cover. Cover the fruit next to the harvest cycle or major plants to protect and improve soil health. Coverfruit provides a dense protective layer that reduces evaporation, increases water infiltration and increases soil moisture retention. Furthermore, the cover fruit improves soil structure, nitrogen rides, and organic matter content that contributes to long-term water conservation (Borrelli et al., 2019) [2].

2.4 Soil Health Management in Horticulture:

Soil health management is an important part of sustainable gardening practices as it is essential to maintain long-term production and promote support for ecosystem functions. The benefits of references that indicate ground health techniques used in horticulture and their effectiveness are discussed in this section. Covered fruits are often used to improve soil health by horticulture. Fruits such as grasses and legumes associated with fallow times or major plants are cultivated for soil protection and accumulation. According to Borelli et al. (2019) [2] Improve soil structure and water retention capacity, increase organic soil content, promote nutrient cycling, and minimize soil erosion. Increased crop yield, reduced nutrient washing, and improved soil biodiversity are the possible consequences of including cover fruit in gardening systems. Another successful method for treating soil health in horticulture is mulch. Mud materials, either organic or inorganic, can be applied to the floor surface to control soil temperature, reduce moisture loss due to evaporation, inhibit weed development, and improve nutrient cycles. Straw, wooden chips, or compost are examples of organic mulch that contribute to the development of organic soil materials, improving soil structure, and promoting soil microbial activity (Borrelli et al., 2019) [2]. Composting and Vermic composting are effective ways to recycle organic waste and increase soil fertility in horticulture. The composting process involves the assembly of organic materials in nutrient-rich soil supplements. Earthworms are used for insect composting to accelerate the collapse of organic matter and to produce insect compost at the highest air. According to Borrelli et al. (2019) [2] and Choudhury et al. (2017) [15]. Both techniques stimulate soil microbial activity, improve soil structure, and increase nutrient availability. Plant rotation is a known method for treating soil health, with various types of harvest being planted in a given order. Harvesting supports a decrease in vegetative organism guards, disrupting the cycle of pests and diseases, and improving soil structure. Gardening systems can successfully handle pest treatments, improve soil biological diversity, and maximize nutrient absorption by diversifying plant species (Borrelli et al., 2019) [2]. Nitrogen treatment and bed testing planning are an integral part of the treatment of soil health in horticulture. Regular soil testing can assess the state of nutrients in the soil and change fertilizers accordingly to make the plants as accessible as possible to the nutrients, while at the same time reducing nutrient loss and environmental impact.

2.5 Biodiversity Enhancement in Horticulture:

Improving biological diversity is an important part of sustainable gardening practices to promote ecological resilience, improve ecosystem services, and enhance general health and productivity in gardening systems. Strategies to improve gardening biodiversity are discussed in this section along with the benefits and evidence of its effectiveness. Improvements in biological diversity in horticulture begin with planting different plant varieties. By including a mixture of culture, flowers and local plants in the horticultural landscape, farmers can provide living space and food sources for a variety of creatures, including pollinators, useful insects, birds and other wildlife. Various plant species help to create a more stable and robust environment that reduces the risk of pest development and promotes natural pest control (Bommarco et al., 2013) [13]. For horticulture to improve biological diversity, local plants and ecosystems must be preserved. Local plants provide important resources for local pollinators and other species, and are well suited to the local environment. Farmers can construct corridors and steps of biological diversity that allow for species movement and connectivity by protecting natural and moisture regions and adding local plants to horticultural landscapes (Kremen et al., 2007) [18]. Manipulating habitats is another way to improve the biological diversity of horticulturality. Including surrounding horticultural systems such as hedges, wild flower stripes, and insect plants in various ecosystems can attract predators, pollinators and useful insects. To support the presence of economic creatures that support pest management and pollination, these environments provide evacuation, nistry and nectar sources

(Landis et al., 2000) [19]. Improved biological diversity in horticulture is also supported by the use of less pesticides and the implementation of IPM technologies (integrated pest management). Farmers can create useful insects such as pollinators and natural enemies by using less broad spectrum insecticides. The use of beneficial species is facilitated by IPM technologies such as biological control and cultural management that reduces the need for chemical interventions and supports healthier and diverse environments (Gontijo et al., 2018) [4].

2.6 Challenges and Barriers to adaptation Knowledge and Awareness Gap:

A lack of understanding of sustainable horticultural techniques can be a major obstacle. According to Bhattarai et al. (2015) [21] Farmers may be subject to the benefits, methods and economic viability of sustainable practices. To bridge this gap in knowledge and to promote the adoption of sustainable practices, educational programs, training courses and expanded services.

Economic restrictions: The introduction of sustainable horticultural practices is often complicated by economic concerns. Farmers can do so before switching to sustainable practices such as organic certification, the introduction of new technologies, and improvements in infrastructure (Ponisio et al., 2015). Economic restrictions are exacerbated by limited access to financial resources, loans, or government incentives.

III. MARKET DEMAND AND ACCESS

Farmers can be discouraged by implementing sustainable gardening practices as market demand is scarce and access to sustainable markets is limited. If the market recognizes and does not reward the environmental benefits of sustainable practices, farmers can be hesitant to invest in these changes (Meemken et al., 2013) [22]. It is important to promote sustainable certification programs, strengthen market debt and develop market incentives to promote the use of sustainable practices.

IV. TECHNICAL COMPLEXITY

Farmers can find it difficult to implement some sustainable horticultural practices, as they may require special knowledge, skills and technical knowledge (Bhattarai et al., 2015) [21]. For example, implementing integrated pest control (IPM) practices requires understanding pest dynamics, monitoring processes, and alternative strategies for pest control. Technical difficulties can be overcome with the use of farmers' training programs, extended services and information exchange.

V. GOVERNMENT AND REGULATORY FACTORS

The implementation of sustainable gardening practices can be hampered by appropriate state support, uneven laws and lack of loose enforcement. According to Meemken et al. (2013) [22] Farmers need to support laws, incentives, and guidelines that promote environmentally friendly practices and promote positive economic situations. The best ways to address these topics are stakeholder collaboration, guidelines lobbying, and efficient regulation implementation.

VI. RECOMMENDATION ON FOR FUTURE RESEARCH

Sustainable horticulture technology has improved agriculture sustainability and promoted environmental care, but there are many topics that require more research and research. The main proposals for future garden training studies are outlined along with the sources supporting them. The effectiveness and potential benefits of sustainable practices can be better understood by longitudinal studies pursuing and analysing long-term effects (Pretty et al., 2018) [28].

VII. ECONOMIC RESTRAINTS

The introduction of sustainable horticultural practices is often complicated by economic concerns. Farmers can do so before switching to sustainable practices such as organic certification, the introduction of new technologies, and improvements in infrastructure (Ponisio et al., 2015). Economic restrictions are exacerbated by limited access to financial resources, loans, or government incentives.

VIII. MARKET DEMAND AND ACCESS:

Farmers can be discouraged by implementing sustainable gardening practices as market demand is scarce and access to sustainable markets is limited. If the market recognizes and does not reward the environmental benefits of sustainable practices, farmers can be hesitant to invest in these changes (Meemken et al., 2013) [22]. Enforcement of sustainable practices requires the accommodation of market bonds, support for sustainable certification programs, and development of market incentives. For example, implementing integrated pest control (IPM) practices requires understanding pest dynamics, monitoring processes, and alternative strategies for pest control. Technical difficulties can be overcome through the use of training programs, extended services, and farmer information exchange.

IX. POLICY AND REGULATION FACTORS

Assumptions about sustainable gardening methods can be hampered by lack of enforcement, inconsistent laws, and inadequate state support. Farmers need supportive guidelines, incentives, and regulations to promote sustainable practices and promote positive economic situations (Meemken et al., 2013) [22]. To overcome these questions, stakeholders must work together, campaign for political change, and ensure that the law is implemented correctly.

X. PRACTICAL IMPLICATIONS FOR PROMOTING

Sustainable horticulture, which promotes sustainable horticulture practices, is extremely important for achieving ecological sustainability and long-term survival of the agricultural sector. This section discusses sources that support practical impacts on improving sustainable horticulture, including methods, methods, and guidelines. Knowledge Transfer and Capacity Structure: It is important to provide farmers with information and training on sustainable gardening methods. Everyone can be extremely useful to spread knowledge and enhance capacity for farmers to pass on sustainable practices, expansion services, training programs, and knowledge exchange platforms for farmers (Dong et al., 2020) [29]. The recognition, understanding, and implementation of sustainable practices stems from effective knowledge transfer. Financial and Political Support: To promote sustainable horticultural practices, governments, politicians and fundraising organizations should provide both financial and political support. To help farmers switch to sustainable practices, this provision includes financial incentives, grants and grants (Seymedi et al., 2020) [31]. Furthermore, Kaufman et al. (2019) [30] is an increase in consumer knowledge of the benefits of sustainably produced horticultural products for the environment and health, which is a critical motivation for promoting sustainable practices. Demand for sustainable, grown horticultural products can be increased by promoting certification programs, environmental characteristics and direct marketing channels. Stakeholder cooperation and commitment: It is important that sustainable horticultural practices are funded to promote cooperation among participants, including farmers, researchers, government organizations, NROs and industry representatives. Multistakeholder platforms, networks and partnerships allow people to share knowledge, collaborate, and collaborate to overcome hiring obstacles (Cameron et al., 2020) [32]. Stakeholder commitments ensure that all perspectives and disciplines are considered and simultaneously promote sustainable practices. Implementing Technology: The introduction of sustainable garden practices can be promoted by introducing technological advances and advances. Production can be increased by maximizing resource consumption, minimizing environmental impacts, and promoting the use of precision agriculture technologies, sensor-based irrigation systems, and digital platforms for monitoring and decision-making (Kang et al., 2017) [26]. It is important to support research and development in these areas so that sustainable technologies can be used successfully in garden construction systems.

XI. CONCLUSION

Sustainable horticulture technologies are important to mitigate negative environmental impacts, promote resource efficiency, and maintain the long-term viability of the horticulture industry. This assessment highlighted many environmentally friendly practices that support long-term horticulture. Gardening systems are more resilient, more resilient and more resilient through organic farming, integrated pest control, water protection, soil health management, improved biological diversity and assessment of environmental outcomes. These environmentally friendly methods offer many benefits, such as improving soil health, reducing chemical input, improving water efficiency, preserving biological diversity, and reducing pollution. Additionally, they support the provision of sustainable livelihoods and safe and healthy foods for farmers. It also strengthens ecosystem services. However, effective implementation of sustainable horticultural practices requires overcoming obstacles and hurdles such as knowledge gaps, financial constraints, market dynamics, technological complexity, and political support. Addressing these challenges requires the introduction of support laws and financial incentives, as well as the participation of a large number of stakeholders, including farmers, academics, political makers and consumers. More research is needed to better understand the long-term impact of sustainable practices, increase climate resilience, use technological advances, address socioeconomic issues, and develop strategies. By accelerating the adoption of sustainable gardening practices, supporting ecological sustainability, and ensuring that the horticultural industry has a more resistant and profitable future by improving understanding of these sectors and guiding its practical results into practice. In summary, eco-friendly agriculture cannot be achieved without the use of sustainable horticultural techniques. The acquisition of these strategies not only provides moral obligations, but also provides a way to develop a more resistant and sustainable horticultural industry that benefits the environment and society as a whole.

REFERENCES

[1] Zaller JG, Heigl F, Ruess L, Grabmaier A, Pachinger B. Organic farming and landscape structure: effects on insect-pollinated plant diversity in intensively managed grasslands. Journal of Applied Ecology. 2019;56(8):1937-1947.

[2] Borrelli P, Panagos P, Märker M, Modugno S, Schütt B. Assessment of the impact of agri-environmental practices on soil erosion and soil fertility. Science of the Total Environment. 2019;650:908-919.

[3] Chaves B, Alegre H, Moriana A, Abadía A, Abadía J. Irrigation strategies to reduce environmental impact in deciduous orchards. Agronomy. 2019;9(7):377.

[4] Gontijo LM, Picanço MC, Pereira RM, Guedes RNC, Pallini A. Conservation biological control in Brazilian crops: Major accomplishments and current challenges. Pest Management Science. 2018;74(11):2528-2536.

[5] Baranski M, Srednicka-Tober D, Volakakis N, Seal C, Sanderson R, Stewart GB, et al. Higher antioxidant and lower cadmium concentrations and lower incidence of pesticide residues in organically grown crops: a systematic literature review and meta-analyses. British Journal of Nutrition. 2014;112(05):794-811.

[6] Bommarco R, Kleijn D, Potts SG. Ecological intensification: harnessing ecosystem services for food security. Trends in Ecology & Evolution. 2013;28(4):230-238.

[7] Hole DG, Perkins AJ, Wilson JD, Alexander IH, Grice PV, Evans AD. Does organic farming benefit biodiversity? Biological Conservation. 2005;122(1):113- 130.

[8] Reganold JP, Glover JD, Andrews PK, Hinman HR. Sustainability of three apple production systems. Nature. 2010;410(6831):926-930.

[9] Parrella MP, Jones VP, Zalom FG. UC IPM Pest Management Guidelines: Floriculture and Ornamental Nurseries. UC ANR Publication 3402. University of California Statewide Integrated Pest Management Program; c2009. Retrieved from http://ipm.ucanr.edu/

[10] Perez G, Gillespie D. Best Practices for Integrated Pest Management (IPM) in Horticulture and Specialty Crops. University of Florida IFAS Extension; c2016. Retrieved from https://edis.ifas.ufl.edu/

[11] Van Lenteren JC, Bale J, Bigler F, Hokkanen HMT, Loomans AJM. Assessing risks and benefits of biological control. IOBC/WPRS Bulletin. 2008;33:9-17.

[12] Wright MG, Hoffmann MP. Integrated Pest Management: Principles and Practice. CABI; c2019.

[13] Lamont WJ. Sustainable water use in horticultural crops. In Environmental Soil and Water Chemistry (2nd ed.,). John Wiley & Sons; c2019. p. 477-490.

[14] Zalewski M, Wagner-Lotkowska I, Valipour M. Water reuse for irrigation of horticultural crops. Water. 2019;11(11):2297.

[15] Choudhury A, Islam M, Uddin, Hossain. Review of vermicomposting as a sustainable approach for managing organic solid waste. in Journal of Environmental Management. 2019;190;140-157.

[16] Aranda V, Gómez-Muoz B, Roldán A. Impacts of cover crops on plant disease prevention and soil microbiology. 1274 in Agronomy; c2020,10(9).

[17] Gómez-Brandón M, Domnguez J, Lores M, Lazcano C. Winery waste vermicomposting: a review. Waste Management. 2013;33(5):1116-1128.

[18] Kremen C, Williams NM, Thorp RW. Crop pollination from native bees at risk from agricultural intensification. Proceedings of the National Academy of Sciences. 2007;104(14):6258-6263.

[19] Landis DA, Wratten SD, Gurr GM. Habitat management to conserve natural enemies of arthropod pests in agriculture. Annual Review of Entomology. 2000;45(1):175-201.

[20] Rader R, Bartomeus I, Garibaldi LA, Garratt MP, Howlett BG, Winfree R, et al. Non-bee insects are important contributors to global crop pollination. Proceedings of the National Academy of Sciences. 2016;113(1):146-151.

[21] Bhattarai B, Conway TM, Steward PR, Khusru S, Lamichhane S, Kader M. Opportunities and challenges for sustainable production and marketing of vegetables in Nepal. Renewable Agriculture and Food Systems. 2015;30(3):205-215.

[22] Meemken EM, Qaim M, Spielman DJ. Trading-off nutrition and pesticide externalities in sustainable agriculture: Evidence from high-value crops in Thailand. Environmental and Resource Economics. 2013;55(4):537-560.

[23] Ponisio LC, M'Gonigle LK, Mace KC, Palomino J, de Valpine P. Diversification practices reduce organic to conventional yield gap. Proceedings of the Royal Society B: Biological Sciences. 2015;282(1799):20141396.

[24] Rana S, Paul RK. Challenges and barriers to adoption of sustainable agricultural practices: Evidence from Indian agriculture. Journal of Cleaner Production. 2021;279:123753.

[25] Chapman SC, Chakraborty S, Dreccer MF, Howden SM, Nigam SN. Plant adaptation to climate change Opportunities and priorities in breeding. Crop Science. 2020;60(6):2577-2594. Kang Y, Hao X, Liu T, Gao P. Precision horticulture: Opportunities, challenges, and technologies. Frontiers in Plant Science. 2017;8:1684.

[26] Popp J, Lakner Z, Harangi-Rákos M, Fári M, Czimbalmos R. The effect of agricultural innovation on the crop production efficiency: Evidence from the European Union. Sustainability. 2020;12(1):338.

[27] Pretty J, Benton TG, Bharucha ZP, Dicks LV, Flora CB, Godfray HC, et al. Global assessment of agricultural system redesign for sustainable intensification. Nature Sustainability. 2018 Aug;1(8):441-6.

[28] Dong Y, Norton T, Bennison J, Knox O. Transition to sustainable horticulture: A systematic review. Journal of Cleaner Production. 2020;243:118606.

[29] Kaufman J, Hand MS, Duff B. Sustainable food systems: An overview. Annual Review of Environment and Resources. 2019;44:227-246.

[30] Seyyedi M, Pourkhabbaz A, Alimirzaie A, Mansoorkhani SH. Sustainable agriculture: A review of challenges and opportunities. Journal of Cleaner Production. 2020;249:119259.

[31] Cameron EE, Joyce KM, Delaquis CP, Reynolds K, Protudjer JL, Roos LE. Maternal psychological distress & mental health service use during the COVID-19 pandemic. Journal of affective disorders. 2020 Nov 1;276:765-74.

[32] Rivera-Pinto J, Egozcue JJ, Pawlowsky-Glahn V, Paredes R, Noguera-Julian M, Calle ML. Balances: a new perspective for microbiome analysis. MSystems. 2018 Aug 28;3(4):e00053-18.

Comprehensive Review on the Role of Religious Beliefs on Dietary Pattern of Population

Nallala Srinija[1*]; Priyanka Shankar[2]; Madhvi Daniel[3]; Kuril Sanjeet[4]

[1]M.Sc. Scholar, Department of Food and Nutrition, Babasaheb Bhimrao Ambedkar University, (A Central University), Lucknow, Uttar Pradesh - 226025, India
[2]Assistant Professor, Department of Food and Nutrition, Babasaheb Bhimrao Ambedkar University, (A Central University), Lucknow, Uttar Pradesh - 226025, India
[3]Resource Person, Department of Food and Nutrition, Babasaheb Bhimrao Ambedkar University, (A Central University), Lucknow, Uttar Pradesh - 226025, India
[4]Research Scholar, Department of Food and Nutrition, Babasaheb Bhimrao Ambedkar University, (A Central University), Lucknow, Uttar Pradesh - 226025, India
*Corresponding Author

Received:- 16 April 2025/ Revised:- 21 April 2025/ Accepted:- 25 April 2025/ Published: 05-05-2025

Abstract— *The influence of religion on food habits in various cultures and societies is examined in this article. Throughout history, religion has strengthened social cohesiveness and cultural identity by influencing dietary preferences, meal plans, and fasting customs. In addition to dictating what is allowed or prohibited, religious beliefs can have an impact on mealtime customs, food preparation techniques, and moral issues around food consumption. In order to comprehend how religious teachings affect both individual and societal food practices, this research synthesizes evidence from a variety of academic sources. The results imply that religion is an important factor in encouraging dietary self-control, creating group meal customs, and influencing laws pertaining to food in both domestic and international settings. The relationship between spiritual beliefs and physical health is emphasized by religious fasting customs including Ramadan in Islam, Lent in Christianity, and fasting rites in Buddhism and Hinduism. Furthermore, dietary patterns influenced by religion support ethical farming, conscientious consumption, and food sustainability initiatives. However, religious dietary traditions face both opportunities and problems from contemporary issues including globalization, dietary shifts, and technical breakthroughs in food production. In order to create culturally responsive nutrition programs and food policies that respect religious diversity while advancing sustainability and health, legislators, medical practitioners, and academics must have a thorough understanding of how religion and dietary habits interact.*

Keywords— Religious beliefs, Dietary Practices, Food Consumption, Health Outcomes, Cultural Identity, Global Food Security.

I. INTRODUCTION

Food is an important part of religious and spiritual activities around the world. Different religious traditions have dietary laws that specify what followers can eat, how they should prepare it, and even when they can eat it. These dietary restrictions are often based on sacred texts, cultural customs, and ethical considerations that direct believers toward particular food choices. Religious dietary laws serve a variety of purposes across different faiths, including establishing moral standards, promoting community identity, and reinforcing spiritual discipline (1,2).

Dietary limitations based on religion also have an impact on public health programs, food markets, and agricultural output, among other broader societal systems. Sociology, anthropology, and nutrition science are among the fields that have begun to examine how religious eating customs have changed and evolved as a result of globalization. Policymakers, nutritionists, and researchers must comprehend these dietary rules in order to create culturally appropriate dietary recommendations and regulations that respect religious convictions while guaranteeing food security and nutritional sufficiency (2,3).

II. RELIGIOUS DIETARY LAWS AND FOOD PRACTICES

2.1 The Historical and Cultural Context of Religious Dietary Laws:

Religious dietary rules have their roots in ancient civilizations thousands of years ago, when food was closely associated with moral principles and religious rites. The kosher dietary regulations in Judaism are outlined in the Torah and place a strong emphasis on ethical slaughter, purity, and the ban on combining dairy and meat. Comparably, Islamic halal dietary regulations, which are based on the Quran and Hadith, govern food intake by outlawing alcohol and pork and requiring humane methods of killing (2,4). Because of the ahimsa (non-violence) principle, which forbids harm to living things, vegetarianism is extensively practiced in Buddhism and Hinduism (2,5).

Fasting and dietary restrictions are also a component of Christianity, especially during holy holidays like Lent when followers refrain from eating meat, dairy, and other luxuries. Eastern Orthodox Christians emphasize self-discipline and spiritual cleansing by observing several fasting periods throughout the year. These religious culinary customs have changed over time, retaining their spiritual underpinnings while adjusting to local cultural factors (2,6).

2.2 The Impact of Religious Dietary Laws on Global Food Systems:

Religious dietary regulations affect food production and international trade in addition to influencing eating habits on an individual and community level. Specialized food industries that serve religious consumers have grown as a result of the rising demand for halal and kosher-certified goods. The economic importance of religious food certifications is demonstrated by the estimated $2 trillion worth of the halal food business alone (2,3). Since many non-Jewish consumers choose kosher products because of their perceived quality and food safety requirements, kosher food markets have also spread beyond of Jewish communities (2,7).

The accessibility and affordability of food are also hampered by religious dietary regulations, notwithstanding the financial advantages. Low-income groups may find it more difficult to obtain halal and kosher items due to the high expense of religious food certifications (2,8). International trade has also been hampered by national regulatory differences, which has sparked discussions about standardizing certifications for religious foods (9). As they negotiate the complexity of religious food markets, policymakers and other stakeholders in the food business must have a thorough understanding of the economic effects of religious dietary regulations.

2.3 Religious Dietary Laws in Contemporary Society:

It is becoming more and more crucial for public organizations to take into account religious dietary restrictions as societies grow more diverse. In an effort to accommodate religious people, schools, hospitals, universities, and prisons now provide vegetarian, halal, and kosher food options (2). Finding a balance between current food laws and nutritional standards and religious dietary requirements is still difficult, though.

Additionally, religious dietary patterns are changing as a result of globalization and changes in food production technology. The popularity of lab-grown meat, genetically modified meals, and plant-based meat substitutes has spurred theological discussions on whether or not these items are allowed under religious dietary regulations (2,10,11). Religious leaders must modify their interpretations of dietary restrictions to take into account contemporary food advancements while preserving the integrity of their religious traditions as food technology advances.

Food has always been more than just sustenance, it carries deep cultural, ethical, and spiritual meaning. Across different faiths, dietary laws reflect religious values, guiding what is permissible to eat, how food should be prepared, and even when meals should be consumed. These traditions help reinforce religious identity, create a sense of belonging within communities, and establish discipline through food-related rituals (12). For centuries, religious dietary rules have shaped societies, influencing agriculture, trade, and even health practices. In Judaism, kosher laws emphasize food purity and humane treatment of animals, while in Islam, halal principles dictate ethical sourcing and preparation methods (13) Arslan and Aydan also. In contrast, Hinduism and Buddhism promote vegetarianism, aligning diet with the spiritual principle of ahimsa, or non-violence, which discourages harm to living beings (2,5).

As societies evolve, religious food practices have adapted to new challenges. Today, globalization has made religious dietary rules more relevant than ever, as people from diverse backgrounds interact in shared spaces like schools, workplaces, and public institutions. This has led to a growing demand for halal, kosher, and vegetarian meal options worldwide, pushing food industries to expand their offerings. Many multinational companies now seek religious food certifications to appeal to a broader consumer base, making faith-based dietary laws an influential force in global food markets (2,3). However, this expansion also brings challenges. Different countries and religious authorities interpret dietary laws in unique ways, leading to inconsistencies in food certification processes. For example, halal certification standards vary between Southeast Asia and the Middle East, creating trade complications and debates over authenticity (2,6).

Advancements in food science and technology have further complicated religious dietary adherence. The rise of genetically modified foods, lab-grown meat, and plant-based meat alternatives has sparked debates within religious communities regarding their acceptability under traditional food laws. Some religious scholars have embraced these innovations as a way to address food security while maintaining religious principles, while others remain cautious, emphasizing the importance of natural and traditional food sources (11). Similarly, modern health research has revealed both benefits and risks associated with religious fasting practices. While intermittent fasting, as observed in Ramadan and Lent, has been linked to metabolic health benefits, prolonged fasting without proper guidance can lead to nutrient deficiencies and dehydration, particularly for individuals with existing health conditions (14). As a result, nutritionists and religious leaders are increasingly working together to develop guidelines that promote both spiritual and physical well-being.

Religious dietary laws also intersect with sustainability and environmental concerns. Many faith-based traditions emphasize mindful eating and responsible food consumption. For instance, the Islamic concept of Tayyib encourages eating wholesome, ethically sourced food, while Christian stewardship promotes reducing food waste and supporting sustainable agriculture (15). As the world grapples with issues like climate change and food scarcity, religious perspectives on food ethics offer valuable insights into creating more sustainable food systems. In this way, religious dietary laws are not only a reflection of faith but also a response to contemporary global challenges, demonstrating how spiritual traditions continue to shape food consumption in meaningful ways.

2.4 Religious dietary laws and food consumption patterns:

Originating from theological beliefs, religious dietary rules are frequently impacted by ethical considerations, historical contexts, and cultural customs. The Torah serves as the basis for Judaism's kosher dietary restrictions, which specify what foods are allowed and what are not, along with stringent rules regarding processing and slaughter. Only some animals that have been killed via the shechita technique are considered permissible, and kashrut laws require that meat and dairy be kept apart (2,16,17) Discipline and spiritual cleanliness are promoted by these food regulations, which also function as religious demands. Because of the perceived quality and food safety regulations, many customers now choose kosher products, extending the reach of kosher food certification beyond Jewish communities

III. DISCUSSION

Dietary habits related to religion have an impact on social, psychological, and economic factors. Through communal meals and religious feasts, food acts as a conduit for cultural preservation, strengthening ties within the community (18). According to social identity theory, following religious food regulations improves both individual self-identification and community cohesiveness (1,2). Furthermore, dietary adherence is influenced by cognitive dissonance because people who violate religious food restrictions may feel uncomfortable, which encourages them to resume following recommended dietary guidelines (1,19).

Economically speaking, the market for food goods with religious certification, such halal and kosher products, has expanded to be worth billions of dollars (2,3,20). Growing consumer awareness and religious observance are expected to propel the global halal food market alone to surpass $2 trillion in the upcoming years. By supporting the ethical treatment of animals and minimizing food waste, religious dietary regulations also support sustainable food consumption (9). However, certain restrictive diets might result in vitamin and mineral shortages, making it difficult to ensure nutritional adequacy (2,6,8).

3.1 Social and Cultural Influence of Religious Diets:

Dietary customs related to religion serve as important components of cultural identity. Food serves as a potent symbol of religious and cultural identity in addition to being a source of nourishment. Following certain dietary guidelines improves ties among the community and keeps customs alive for future generations (21). Religiously significant meals bring families and communities together, and through eating rituals, cultural values and moral lessons are reinforced. For instance, the Islamic custom of sharing a meal during Ramadan or the Jewish custom of keeping kosher regulations during Passover both enhance social cohesiveness and religious identification (1,2). Similarly, communal vegetarian meals during religious festivals in Buddhist and Hindu cultures emphasize spiritual and ethical commitments to mindfulness and non-violence (2,5).

However, there are issues in multicultural communities where mainstream food culture and religious dietary requirements collide. It may be challenging for people who follow rigorous religious diets to find suitable food selections in public settings including workplaces, hospitals, and schools. Many establishments have responded by providing vegetarian, kosher, or halal meal options, guaranteeing religious groups' inclusion (6). As a result of the growth of diaspora populations and international migration, local cuisines and religious dietary regulations have been combined to create hybrid food traditions that preserve religious authenticity while embracing cultural variety (8).

3.2 Psychological and Behavioural Implications of Religious Diets:

Religious food regulations have a profound impact on self-discipline, self-control, and mental health since they are ingrained in individual psychology. Adhering to dietary limits necessitates deliberate decision-making, strengthening moral and ethical values. According to the cognitive dissonance theory, those who adhere to religious dietary regulations to the letter have a sense of internal harmony as their beliefs and behaviours coincide psychologically (17). This explains why many religious followers say that following food restrictions makes them feel more satisfied and fulfilled spiritually.

There are psychological advantages to religious fasting, such as intermittent fasting during Lent or Ramadan, such as improved emotional resilience, mindfulness, and self-discipline (2,11). Self-control, appreciation, and introspection are fostered by these fasting practices, and they may have beneficial effects on mental health. Individual experiences, however, may also influence the psychological effects of religious food restrictions. When traveling, being sick, or not having access to meals that are authorized by their religion, some people may feel guilty or anxious about not being able to follow stringent dietary regulations (2).

3.3 Economic Impact of Religious Food Markets:

The growth of international food enterprises serving particular religious markets has been facilitated by religious dietary regulations. Due to rising consumer demand for items with religious certification, the halal and kosher food industries have expanded dramatically over the last 20 years (2,3). The growing Muslim population and non-Muslim consumers' growing desire for halal-certified products, which they view as superior and ethically sourced, are expected to propel the worldwide halal food market alone to surpass two billion dollars in the upcoming years (2,4).

Since many consumers choose kosher-certified products because of their perceived cleanliness, safety, and strict food handling requirements, the kosher food sector has also grown beyond of Jewish communities (2,7). Global food supply chains now face difficulties as well as new economic opportunities as a result of the growth of religious food certifications and the creation of international regulatory agencies that monitor adherence to religious dietary regulations.

Some issues still exist in religious food markets, despite economic prosperity. Low-income groups may find these items less accessible due to the high expense of halal and kosher food certification (8). Additionally, disparities in halal and kosher certification requirements among nations have complicated commerce and necessitated efforts by stakeholders in the food business to harmonize (9). These financial difficulties emphasize the necessity of laws that guarantee reasonable prices and easy access to foods that adhere to religious beliefs in general marketplaces.

3.4 Health Implications of Religious Diets:

Dietary regulations based on religion can have both beneficial and detrimental health effects. Plant-based eating, complete foods, and moderation are key components of many religious diets, which improve general health. For instance, because Hindu and Buddhist vegetarian diets emphasize a high consumption of nutrient-dense, fibre-rich foods, they have been associated with decreased risks of obesity, cardiovascular disease, and several types of cancer (5). Both Islam and Christianity have linked fasting to metabolic advantages, such as increased fat metabolism, decreased inflammation, and higher insulin sensitivity (11,22).

However, if not properly managed, stringent religious diets can also be harmful to one's health. Deficits in vital nutrients including vitamin B12, iron, and omega-3 fatty acids might result from dietary regulations that restrict particular food groups (6). For instance, Jainism's rigorous vegetarianism, which forbids the use of animal products and root vegetables, may lead to vitamin deficiencies that call for careful meal planning (8). Dehydration, exhaustion, and compromised immune function can also result from prolonged fasting without enough hydration and nutrient intake (9,23).

To create culturally appropriate dietary recommendations that guarantee adequate nutrition while honoring religious convictions, healthcare professionals and dietitians must collaborate closely with religious communities. Education and awareness of nutrient-dense food choices within the limitations of religious dietary regulations should be the main emphasis of public health campaigns (2).

3.5 Policy and Institutional Adaptations to Religious Dietary Needs:

Policies that support religious dietary practices in public institutions are becoming more and more necessary as religious diversity in many cultures grows. In order to guarantee that halal, kosher, and vegetarian food options are available in schools, colleges, hospitals, and prisons, numerous governments and organizations have put laws into place. These regulations address any dietary health issues while simultaneously fostering diversity and respect for religious freedom (2,3).

Clear certification markings for items that comply with religious beliefs have been added to food labeling requirements in several nations, making it simpler for customers to choose appropriate options (2,4). In order to ensure that religious customers have access to foods that are both ethically and religiously accepted across various locations, the establishment of worldwide halal and kosher certification agencies has enabled trade and standardization (9). Nonetheless, there are still issues with preventing fraud in religious food certifications and implementing uniform labeling requirements (6).

Some public measures have also come under fire for inadvertently making food access more difficult or for not being inclusive enough. For example, in certain nations, discussions about religious slaughter practices have surfaced, with worries about animal welfare regulations clashing with halal and kosher slaughter practices (8). In multicultural nations, striking a balance between religious freedom and ethical food laws continues to be a crucial topic of policy debate.

3.6 The Future of Religious Dietary Practices in a Globalized World:

Religious dietary customs are changing along with the ways that globalization continues to influence food consumption habits. Religious societies' interpretations and adaptations of their dietary restrictions have been impacted by the growth of plant-based substitutes, increased cross-cultural interactions, and technical developments in food production (2,3). Future studies ought to concentrate on the effects that new food technology and shifting consumer habits will have on sustainability and compliance with religious dietary regulations (11). Furthermore, in order to guarantee fair access to foods that adhere to religious beliefs while tackling more general issues related to global food security, policy frameworks must keep changing (9).

IV. CONCLUSION

Global food security, cultural identity, economic markets, and health are all significantly impacted by religious dietary traditions. They offer a framework that helps people and groups make moral dietary decisions while preserving their cultural customs and spiritual values. These dietary regulations have many advantages, such encouraging self-control, fortifying social ties, and encouraging sustainable food usage, but they also have drawbacks.

The findings of this review highlight the profound impact of religious dietary laws on health, culture, economy, and environmental sustainability. Across different faiths, dietary restrictions shape individual food choices, reinforce cultural identity, and promote ethical food consumption. Religious dietary laws also play a crucial role in the global food industry, influencing markets and regulatory frameworks. The growing demand for halal, kosher, and vegetarian-certified foods demonstrates that faith-based dietary practices continue to be relevant in today's world.

From a health perspective, religious food practices have both benefits and risks. While fasting and plant-based diets in various religions have been linked to improved metabolism and heart health, restrictive food laws can sometimes lead to nutrient deficiencies if not carefully managed. The collaboration between religious authorities and health professionals is crucial in ensuring that religious dietary practices remain both spiritually meaningful and nutritionally balanced.

The implications of religious dietary laws extend beyond personal food choices, affecting food policies and social inclusivity. Many countries are now incorporating religious dietary accommodations in public institutions to ensure that diverse populations have access to food that aligns with their faith. However, challenges such as inconsistencies in food certification, accessibility issues, and economic disparities continue to pose obstacles to equitable food access for religious communities.

Moving forward, it is essential to integrate religious perspectives into broader discussions on sustainability and ethical food production. Faith-based traditions that emphasize mindful eating, humane treatment of animals, and sustainable agriculture can contribute to global efforts in combating climate change and reducing food waste. Future research should explore how technological advancements, such as lab-grown meat and alternative proteins, can be adapted to religious dietary frameworks without compromising spiritual integrity.

As a result, religious dietary regulations are firmly anchored in social cohesiveness, ethical duty, and cultural legacy and go beyond simple food limitations. As cultures change, maintaining a balance between tradition and modernity will require ongoing discussions between religious scholars, decision-makers, and nutrition specialists. We can guarantee that religious dietary laws are applicable and advantageous for upcoming generations by encouraging an inclusive and sustainable approach to religious eating practices.

REFERENCES

[1] Emmons, R. A. (2005). Striving for the sacred: Personal goals, life meaning, and religion. *Journal of social issues*, *61*(4), 731-745.

[2] Arslan, S., & Aydın, A. (2024). Religious Dietary Practices: Health Outcomes and Psychological Insights From Various Countries. *Journal of religion and health*, *63*(5), 3256-3273.

[3] Alonso, E. B. (2015). The impact of culture, religion and traditional knowledge on food and nutrition security in developing countries.

[4] Qadri, H. M. U. D. (2024). *The global halal industry: A research companion*. Taylor & Francis.

[5] Chouraqui, J. P., Turck, D., Briend, A., Darmaun, D., Bocquet, A., Feillet, F., ... & Committee on Nutrition of the French Society of Pediatrics. (2021). Religious dietary rules and their potential nutritional and health consequences. *International journal of epidemiology*, *50*(1), 12-26.

[6] Redecillas-Ferreiro, S., Moráis-López, A., & Moreno-Villares, J. M. (2020). Position paper on vegetarian diets in infants and children. Committee on Nutrition and Breastfeeding of the Spanish Paediatric Association. *Anales de Pediatría (English Edition)*, *92*(5), 306-e1.

[7] Kraemer, D. C. (2020). *Jewish eating and identity through the ages*. Routledge.

[8] Wang, T., Masedunskas, A., Willett, W. C., & Fontana, L. (2023). Vegetarian and vegan diets: benefits and drawbacks. *European heart journal*, *44*(36), 3423-3439.

[9] Alshayig, K. (2024). *Examining Consumer Motives That Affect Consumption Intentions For Religious Recommended Foods* (Doctoral dissertation, Griffith University).

[10] Atayee-Bennett, E. (2024). Purity and pollution: faith vegans' categorizations of plant-based foods as pure and animal-derived foods as polluting. *Food, Culture & Society*, 1-18.

[11] Peles, C., Shloim, N., & Rudolf, M. C. (2021). "Over-preoccupation with healthy food is perceived as worship of the body": Food, culture and beliefs in Ultra-Orthodox Jewish families. *Appetite*, *167*, 105621.

[12] Harvey, G. (2015). Respectfully eating or not eating: putting food at the centre of Religious Studies. *Scripta Instituti Donneriani Aboensis*, *26*, 32-46.

[13] Rosenblum, J. D. (2014). Food and identity in early rabbinic Judaism. In *Meals in early Judaism: Social formation at the table* (pp. 59-70). New York: Palgrave Macmillan US.

[14] Heiman, A., Just, D., McWilliams, B., & Zilberman, D. (2004). Religion, religiosity, lifestyles and food consumption. *ARE Update*, *8*, 9-11.

[15] Fenkl, E. A., & Purnell, L. D. (Eds.). (2024). *Handbook for culturally competent care*. Springer.

[16] Avieli, N., & Markowitz, F. (Eds.). (2023). *Eating Religiously: Food and Faith in the 21st Century*. Taylor & Francis.

[17] Plante, C. N., Rosenfeld, D. L., Plante, M., & Reysen, S. (2019). The role of social identity motivation in dietary attitudes and behaviors among vegetarians. *Appetite*, *141*, 104307.

[18] Sunita Mishra et al., 2021. Assessment of Covid-19 Lockdown on Health Status of the Population. Ijppr.Human, 2021; Vol. 22 (3): 631-642.

[19] Sanjeet[1], K., Mishra[1], S., Sharmila, K., & Malik, B. B. (2021). Impact of the Covid-19 Pandemic on Lifestyle and Well Being of Population. Ind. J. Pure App. Biosci, 9(3), 64-72.

[20] Sanjeet, K., & Yadav, S. (2024) Nourishing the Self: Exploring the Significance of Satvik Diet in Yoga Practice.

[21] Sanjeet, K., & Mishra, S. (2023). Recent Developments in Food Preservation Techniques: A Review. TWIST, 18(4), 287-296.

[22] Sanjeet, K., & Mishra, S. (2025). Behind bars: Evaluating the nutritional landscape—A review of dietary patterns provided in correctional facilities. Food systems, 7(4), 585-589.

[23] Daniel, M., & Pandey, H. MILLETS.

Mutation Breeding in Fruit Crops: Historical Milestones, Technological Advances, and Practical Applications

Ronak Kuri[1*]; Santosh Kumar Jakhar[2]; Naresh Kumar[3]; Santosh Choudhary[4]; Mahesh Kumar Poonia[5]

[*1]Ph.D. scholar Department of Horticulture, Agriculture University, Jodhpur, Rajasthan 342304, India.
[2]Master's Scholar, Department of Animal Science, Palli Siksha Bhavana (Institute of Agriculture) Visva-Bharati Sriniketan, West Bengal, India
[3]Ph.D. scholar Department of Agronomy, Agriculture University, Jodhpur, Rajasthan 342304, India.
[4]Assistant Professor, Department of Horticulture, Agriculture University, Jodhpur, Rajasthan 342304, India.
[5]Professor, Department of Horticulture, Agriculture University, Jodhpur, Rajasthan 342304, India.
*Corresponding Author

Received:- 18 April 2025/ Revised:- 27 April 2025/ Accepted:- 30 April 2025/ Published: 05-05-2025

Abstract— *Mutation breeding offers an effective strategy for the genetic improvement of fruit crops, particularly those hindered by long juvenile phases, complex reproductive barriers, or limited genetic variability. By inducing heritable changes using physical (e.g., gamma rays, X-rays, ion beams) or chemical (e.g., EMS, sodium azide) mutagens, desirable traits can be introduced without disrupting the overall genetic integrity of elite cultivars. Historically, mutation breeding began in the early 20th century and has since led to the official release of over 3,000 improved crop varieties worldwide. Key achievements include the development of disease-resistant, seedless, dwarf, and early-maturing cultivars in species such as Japanese pear, guava, papaya, and banana. The use of in vitro techniques like somatic embryogenesis and cell suspension cultures has enhanced mutation efficiency, especially in vegetative propagated crops, by reducing chimerism and allowing high-throughput screening. Recent advancements such as TILLING, EcoTILLING, and insertional mutagenesis (via T-DNA and transposons) enable precise gene targeting and rapid identification of mutant alleles. Molecular markers and tissue culture-based selection techniques further accelerate the breeding cycle and improve selection accuracy. Success in mutation breeding depends on factors such as optimal mutagen dose, treatment duration, tissue sensitivity, and genotype. Strategic integration of traditional mutation techniques with modern biotechnological tools has greatly improved the ability to develop superior fruit cultivars with enhanced tolerance to biotic and abiotic stresses, improved quality, and better adaptability. Mutation breeding thus remains a valuable approach in sustainable fruit crop improvement.*

Keywords— Mutation breeding; Fruit crop improvement; Induced mutagenesis; In vitro techniques; Molecular markers.

I. INTRODUCTION

Genetic improvement plays a crucial role in enhancing the productivity of fruit crops (Rugini et al., 2020). However, tree fruit breeding faces several challenges, including extended juvenile periods, the lack of suitable germplasm, and the typically large size of the trees. Additionally, controlled breeding in many fruit crops is hindered by issues like delayed flowering, poor fruit setting due to abortive embryos, and significant fruit drop. Even when successful fruit varieties exist, they often come with various agronomic and horticultural challenges. One of the key methods in improving fruit trees is harnessing genetic variation, whether natural or induced. When desirable traits are absent in existing cultivated varieties or when a high-yielding variety is compromised by genetic defects, such as disease susceptibility, mutation breeding can be an effective solution. This approach is especially useful in cases where there is a strong linkage between beneficial and undesirable traits. Moreover, in fruit crops where sexual reproduction is absent, or the breeding cycle is exceptionally long, induced mutations can help generate new variability and break the limitations posed by these factors (Sattar et al., 2021). One notable obstacle in fruit breeding is the reluctance of growers to adopt new varieties, which limits the potential of cross-breeding. In addition, specific challenges such as polyploidy, incompatibility, and apomixis can make it difficult to obtain useful recombinants. Mutation breeding, however, offers an efficient alternative by inducing changes in specific traits of an elite cultivar without disrupting the broader characteristics demanded by the fruit industry and consumers.

Mutations refer to heritable changes in the phenotype of an organism, caused by chemical alterations at the genetic level (Nei, 2007). These alterations can lead to new heritable traits in plants, which can be selected for and utilized in developing new crop varieties with improved characteristics. The frequency of mutations can be increased by using various mutagens, and these mutations are referred to as induced mutations. A mutant variety is a new plant variety that results from mutagenesis or somaclonal variation. Mutant varieties can be developed in different ways:

1. Direct use of a mutant line, which is generated through mutagenesis or somaclonal variation.
2. Indirect use of a mutant line, where the mutant serves as a parent in cross-breeding programs.
3. Use of a specific mutant gene or allele, which imparts a desired trait.
4. Utilization of genes from wild species, which are introduced into the plant's genome through irradiation or mutagen-induced translocations.

Mutation breeding is particularly beneficial in overcoming the constraints of conventional breeding methods, enabling faster development of improved fruit varieties with desirable traits.

II. HISTORICAL BACKGROUND OF PLANT MUTATION BREEDING

The concept of plant mutations dates back to as early as 300 BC, with ancient records from China mentioning unusual variations in cultivated crops. However, the scientific understanding of mutations as a mechanism of generating variability began to take shape in the late 19th century, thanks to the pioneering work of Dutch botanist Hugo de Vries (Theunissen, 1998). While studying evening primrose (*Oenothera*), de Vries observed sudden and heritable changes in plants that could not be explained by the traditional Mendelian concepts of segregation and recombination. He described these abrupt, inheritable changes as "mutations," a term he introduced to the scientific community, laying the foundation for mutation theory in genetics. The practical application of mutation breeding gained momentum with the discovery of the mutagenic effects of X-rays, a breakthrough attributed to Lewis J. Stadler in the 1920s. Stadler's experiments demonstrated that exposure to X-rays could artificially induce mutations in plant genomes, thereby expanding the potential for creating genetic diversity beyond natural limits. The first successful commercial application of this technique was achieved in 1934 with the development of a mutant tobacco variety. This milestone marked the beginning of mutation breeding as a practical plant improvement strategy. From the 1950s onward, the use of mutagenesis—particularly through radiation—became widespread in global breeding programs. During this period, a wide array of crops, including cereals, legumes, vegetables, and ornamentals, were treated with physical (e.g., gamma rays, X-rays) and chemical mutagens (e.g., EMS, sodium azide) to induce variability in traits such as disease resistance, plant stature, yield, maturity, and quality.

The success of mutation breeding lies in its ability to create precise genetic changes without significantly altering the overall genetic background of elite cultivars. This characteristic makes it especially attractive for crops where conventional hybridization is limited by biological or agronomic constraints. To date, more than 3,300 officially released mutant varieties have been recorded worldwide, with significant contributions to food security, crop resilience, and nutritional improvement (FAO/IAEA Mutant Variety Database). Mutation breeding has thus evolved from a theoretical genetic concept into a robust and targeted tool in modern crop improvement programs (Oladosu *et al*., 2016).

III. MUTAGENESIS IN CROP IMPROVEMENT

Induced mutagenesis has emerged as a pivotal tool in the genetic enhancement of crop plants, especially in fruit crops where traditional breeding is limited by biological constraints (Oladosu et al., 2016). Through the application of physical or chemical mutagens, breeders have been able to generate novel genetic variations that contribute to the development of superior cultivars. The major applications of induced mutations in crop improvement include:

1. Development of improved cultivars with traits such as earliness, higher yield, and better quality.
2. Induction of male sterility, facilitating hybrid seed production.
3. Production of haploids, enabling homozygous lines for breeding.
4. Creation of genetic variability in otherwise uniform cultivars.

5. Overcoming self-incompatibility, improving pollination and fruit set.
6. Enhancement of adaptation, including stress tolerance and wide adaptability.

TABLE 1
NOTABLE MUTANT TRAITS DEVELOPED IN MAJOR FRUIT CROPS THROUGH INDUCED MUTAGENESIS

Fruit	Mutant Traits Developed	Fruit	Mutant Traits Developed
Apple	Early maturity, red skin color, compact tree, russet-free fruit skin, variegated leaf	Loquat	Larger fruit size
Pear	Resistance to diseases	Pomegranate	Dwarf plant stature
Peach	Increased fruit size and yield, disease resistance	Papaya	Dwarfness
Citrus	Seedlessness, red pigmentation in fruit and juice	Japanese Pear	Disease resistance
Apricot	Early maturity	Indian Jujube	Early maturity, fruit shape variation
Plum	Early flowering	Banana	Earliness, improved bunch size
Pineapple	Spineless variants	Apricot (again)	Earliness

(Source: Jain, 2002)

3.1 Fruit Crops with High Potential for Mutation Breeding:

The following fruit crops have shown considerable scope for genetic improvement through induced mutation techniques:

TABLE 2
POTENTIAL FRUIT CROPS FOR GENETIC IMPROVEMENT VIA INDUCED MUTATION BREEDING

Fruit Crop	Target Traits for Improvement
Mango	Disease resistance, flavour improvement, stress tolerance, amenability to in vitro techniques
Date Palm	Bayoud disease resistance, creation of favorable microclimates in semi-arid regions
Coconut	Improvement as a staple in coastal and island ecosystems
Cashew	Higher yield, abiotic stress tolerance, better kernel quality
Avocado	Rootstock resistance to *Phytophthora* root rot
Papaya	Short cropping duration, resistance to papaya ringspot virus, delayed ripening
Citrus spp.	Seedlessness, disease resistance, water-use efficiency, compatibility with molecular breeding
Carambola	Compact plant habit, sub-acid flavor, self-compatibility
Jujube	Better fruit quality, early blooming, resistance to diseases, color and shape variants
Guava	Early flowering, seedlessness, tolerance to abiotic and biotic stresses
Annona spp.	Dwarf plants, extended shelf-life, fewer or smaller seeds
Litchi	Smaller seeds, extended harvest period
Banana	Resistance to nematodes and *Black Sigatoka* disease

(Source: Jain, 2002)

Mutation breeding, particularly when integrated with tissue culture, molecular marker-assisted selection, and genomic tools, can accelerate the development of elite varieties. Advances in technologies like CRISPR/Cas9 gene editing, TILLING (Targeting Induced Local Lesions IN Genomes), and genome-wide mutation screening have further refined the precision and applicability of induced mutations in perennial fruit crops (Singh et al., 2024). These approaches help in tailoring specific traits without disturbing the overall genetic makeup and consumer acceptance of established cultivars.

IV. PROCEDURE OF MUTATION BREEDING

Mutation breeding involves three primary types of mutagenesis:

1. **Induced Mutagenesis** – Mutations caused by exposure to physical agents like gamma rays, X-rays, ion beams, or chemical mutagens.

2. **Site-Directed Mutagenesis** – Specific changes introduced at target DNA sequences.
3. **Insertional Mutagenesis** – Genetic alterations via DNA insertions using methods such as T-DNA transformation or activation of transposable elements (Oladosu et al., 2016).

A critical step in this process is mutant screening and confirmation. Screening helps identify individuals with the desired mutations, while confirmation ensures the exclusion of false positives (Oladosu et al., 2016).

4.1 Mutagenic Agents:

Mutagens are broadly classified as:

- Physical Mutagens (e.g., gamma rays, X-rays, ion beams)
- Chemical Mutagens (e.g., EMS, sodium azide)

Mutation induction can be performed on various plant materials including seeds, seedlings, and in vitro cultured tissues. While seeds are traditionally used, modern techniques increasingly employ vegetative propagules and explants like leaf discs, stem pieces, calli, anthers, microspores, ovules, and protoplasts for inducing mutations.

Chemical mutagens are often preferred for creating point mutations. Physical mutagens are used to induce larger genetic changes like chromosomal rearrangements. Notably, mutation frequency and type depend more on the dose and exposure duration than the mutagen type.

4.2 Physical Mutagenesis:

Physical mutagens offer precise and reproducible results, especially gamma rays due to their uniform tissue penetration (Oladosu et al., 2016).

Commonly, the LD_{50} dose (lethal dose for 50% of the treated population) is used, but this may cause high mortality and overshadow useful mutations. A more practical approach is using lower lethality doses (e.g., LD_{20}) that ensure better survival (up to 80%), improving the chances of retaining beneficial mutants.

4.3 Chemical Mutagenesis:

Chemical mutagens generally act more gently and do not require sophisticated equipment.

These are effective in generating a higher ratio of desirable mutations compared to physical mutagens. However, they often pose health hazards (e.g., carcinogenicity), necessitating strict safety measures. Factors such as mutagen concentration, treatment duration, and temperature influence the efficiency of chemical mutagenesis (Kodym and Afza, 2003). Due to their high reactivity, it is essential to use freshly prepared solutions of chemical mutagens.

TABLE 3
COMMONLY USED PHYSICAL MUTAGENS

Mutagen	Source	Key Characteristics	Hazard Level
X-rays	X-ray machine	Electromagnetic radiation; penetrates several mm to cm into tissues	Dangerous, penetrating
Gamma Rays	Radioisotopes (^{60}Co, ^{137}Cs)	Deeply penetrating electromagnetic radiation from isotopes or nuclear reactors	Very dangerous, highly penetrating
Neutrons	Reactors or accelerators	Uncharged particles (fast, slow, thermal); deep tissue penetration	Extremely hazardous
Beta Particles	Radioisotopes (^{32}P, ^{14}C)	Ionizing electrons; shallow penetration	Potentially hazardous
Alpha Particles	Radioisotopes	He nuclei; strong ionization; minimal penetration	Very dangerous
Protons	Nuclear reactors/accelerators	Hydrogen nuclei; penetrate several cm into tissues	Very dangerous
Ion Beam	Particle accelerators	High-speed ions (20–80% speed of light); high energy deposition	Dangerous

(Source: Oladosu et al., 2016)

TABLE 4
COMMONLY USED CHEMICAL MUTAGENS

Mutagen Type	Examples	Mode of Action
Alkylating Agents	EMS, MMS, DMS, MNU, ENU, DES, MNNG, NDMA, NDEA	Add ethyl/methyl groups to DNA bases, causing mispairing or base loss leading to mutations
Azide	Sodium azide	Similar to alkylating agents
Hydroxylamine	Hydroxylamine	Similar to alkylating agents
Antibiotics	Actinomycin D, mitomycin C, azaserine, streptonigrin	Induce chromosomal aberrations; may cause cytoplasmic male sterility
Nitrous Acid	Nitrous acid	Deaminates cytosine to uracil, leading to transition mutations
Acridines	Acridine orange	Intercalate into DNA, causing frame-shift mutations by distorting DNA helix
Base Analogues	5-BU, 2AP, Maleic hydrazide, 5-BdU	Mimic normal bases, cause base transitions and tautomeric shifts during DNA replication

(Source: Oladosu et al., 2016)

V. TYPES OF MUTATIONS

Mutations can be broadly categorized into the following types based on their location and nature:

5.1 Intragenic or Point Mutations:

These occur within a single gene, involving changes in the DNA sequence such as base substitutions, deletions, or insertions (Zhang and Gerstein, 2003). When insertions or deletions are not in multiples of three nucleotides, they cause frame-shift mutations, which can significantly disrupt gene function by altering the reading frame. Even the insertion or deletion of a single base pair can render a gene non-functional.

5.2 Intergenic or Structural Mutations (Chromosomal Rearrangements):

These involve larger-scale changes in chromosome structure and typically result from chromosome breakage and incorrect rejoining (Lu et al., 2025). Ionizing radiation is a common cause of such mutations. Structural mutations are classified into:

- **Deletions (Deficiencies)**: Loss of chromosome segments; often lethal but can also disrupt specific biochemical pathways.
- **Duplications**: Repetition of chromosome segments; have played a significant role in the evolution of diploid crops.
- **Inversions**: A chromosome segment is reversed end-to-end (180° rotation); common in crop genomes.
- **Translocations**: Exchange of segments between non-homologous chromosomes; frequently observed in plant breeding.

Approximately 90% of chromosomal aberrations induced by ionizing radiation are deletions, many of which lead to lethality (Pathirana, 2011).

5.3 Genome Mutations (Changes in Chromosome Number):

These mutations involve alterations in the entire set or number of chromosomes. They are primarily of three types:

- **Autopolyploidy**: Multiple sets of chromosomes derived from the same species.
- **Allopolyploidy**: Combination of genomes from different species through interspecific or intergeneric hybridization followed by chromosome doubling.
- **Aneuploidy**: Loss or gain of one or a few chromosomes, leading to an unbalanced genome.

5.4 Nuclear vs. Extranuclear (Plasmone) Mutations:

Mutations can also be classified based on their genetic location:

- Nuclear mutations affect the DNA within the chromosomes in the nucleus.
- Extranuclear (Plasmone) mutations occur in organelles such as mitochondria and chloroplasts, and can influence traits like cytoplasmic male sterility.

VI. NEW METHODS FOR MUTATION INDUCTION

Over the past two decades, rapid advancements in in vitro plant tissue and cell culture techniques have significantly enhanced the efficiency of mutation breeding, especially in vegetatively propagated crops such as *banana* and *Citrus* spp. (Pathirana, 2011). These methods offer several key advantages:

- High-throughput mutant production in limited space.
- Controlled laboratory screening for stress-related traits like salt tolerance, resistance to toxic elements, or fungal toxins.
- Pre-selection of promising mutants prior to field trials, reducing time and resources.
- Elimination of chimeras through successive subcultures in clonal crops.

Such protocols have been successfully standardized for important crops like banana, facilitating the generation and evaluation of large mutant populations under controlled conditions.

6.1 Insertional Mutagenesis:

Insertional mutagenesis serves as a powerful approach for generating targeted mutants, particularly for functional genomics studies, as the induced mutations are tagged with known DNA sequences. Two major techniques are employed:

1. T-DNA Insertion: Utilizes *Agrobacterium tumefaciens* to introduce T-DNA fragments into plant genomes. These are considered genetically modified organisms (GMOs) due to the presence of foreign DNA (Gelvin, 2017).

2. Transposon Tagging: Relies on mobile genetic elements (transposons) naturally present in the plant genome. When activated, transposons move to new genomic locations, creating mutations. This method is increasingly utilized in mutation breeding as a non-GMO tool for gene disruption and trait discovery (Ben-Amar et al., 2016).

VII. RECENT ADVANCES IN MUTATION BREEDING

Modern biotechnological advancements have significantly enhanced the efficiency and precision of mutation breeding, especially in fruit crops. Techniques such as tissue culture and molecular biology are now being effectively combined with conventional breeding to create, identify, and propagate desirable mutations (Jain, 2002).

Biotechnological Tools: Somatic embryogenesis; Somaclonal variation; Micropropagation & micrografting; Cryopreservation of embryogenic cultures; In vitro selection under stress; Somatic hybridization and Embryo rescue.

7.1 In Vitro Mutagenesis:

Using in vitro techniques for mutation induction offers several advantages: Allows mutation in a large number of propagules within limited space. Enables repeated subcultures to separate mutated from non-mutated tissues. Somatic embryogenic cultures derived from a single cell reduce chimerism risk. Budwood or seeds may be irradiated if somatic embryogenesis delays flowering. Multiple grafting cycles help overcome any residual chimerism.

7.2 In Vitro Selection of Mutants:

This approach involves applying selection pressure (e.g., salt, phytotoxins) on irradiated cultures (callus, protoplasts, or cell suspensions). Regenerated plants are then screened in greenhouse or field conditions.

- Example: Strawberry mutants showing resistance to *Phytophthora cactorum*.
- Molecular markers are used to confirm genetic changes.

TABLE 5
IN VITRO MUTAGENESIS IN VEGETATIVELY PROPAGATED CROPS

Crop	Treated Material	Mutagen & Dose	Regeneration	Selected Traits
Banana	Shoot tips	Carbon-ion beam (0.5–128 Gy)	Direct regeneration	Disease resistance
Banana	Shoot tips	γ-rays (60 Gy)	Direct regeneration	Earliness (Mutant: Novaria)
Banana (var. Lakatan, Latundan)	Shoot tips	γ-rays (25–40 Gy)	Direct regeneration	Dwarfism, larger fruit size
Pineapple (var. Queen)	Crowns	γ-rays	Axillary bud regeneration	Reduced spine density
Pear	In vitro shoots	γ-rays (3.5 Gy)	Shoot microcuttings	Changes in russeting, fruit size, tree architecture

TABLE 6
SELECTABLE AGRONOMIC TRAITS IN CELL CULTURES

Trait	Selection Agent
Disease resistance	Pathotoxins / Crude toxins / Culture filtrates
Herbicide tolerance	Herbicides
Salt tolerance	High NaCl / Seawater
Metal tolerance	Toxic metal concentrations
Cold tolerance	Exposure to low temperatures
Drought tolerance	Polyethylene glycol (PEG) / High osmoticum
Enhanced amino acid content	Amino acid analogues or high doses
Flooding tolerance	Anaerobic growing conditions

(Source: Suprasanna et al., 2015)

TABLE 7
DNA MARKERS FOR GENETIC VARIATION ANALYSIS

Category	Marker Types
Genomic DNA (Restriction-based)	RFLP (Restriction Fragment Length Polymorphism)
PCR-based Markers	RAPD, SCAR, SSR, EST-SSR, ISSR, SNP, SRAP, ASAP, VNTR, STS
PCR + Restriction Combination	AFLP (Amplified Fragment Length Polymorphism), CAPS
Array-based Markers	DArT (Diversity Array Technology), Microarray, Bead Array

VIII. STRATEGIES FOR MITIGATING DRAWBACKS IN MUTATION INDUCTION IN FRUIT CROPS

While mutation breeding offers great potential, especially in vegetatively propagated and perennial fruit crops, it faces several technical challenges. These include low mutation efficiency, chimerism, and the difficulty of obtaining homozygous recessive mutants. However, strategic integration of cellular, tissue culture, and molecular biology tools can help overcome these limitations (Mba et al., 2013).

8.1 Cellular and Tissue Biology Strategies

One of the primary issues in induced mutation breeding is the low efficiency and quality of mutant populations. In vegetatively propagated crops, chimerism—where only part of a plant carries the mutation—is a major hurdle. Furthermore, because many beneficial mutations are recessive, achieving homozygosity is essential for trait expression. Several in vitro culture systems, such as cell suspensions and somatic embryogenesis, have shown promising results in overcoming these challenges.

8.2 Somatic Embryogenesis:

Somatic embryogenesis, which involves regenerating whole plants from single cells, offers a solution to both chimerism and low mutation frequency. The process begins with the proliferation of undifferentiated callus, which is then induced into embryogenic cells. These are exposed to mutagens, and due to the totipotency of plant cells, complete plants are regenerated from these single cells. As each regenerated plant originates from a single mutated cell, they are free from chimerism. This method has been successfully used to produce mutant banana lines (Mba et al., 2013).

8.3 Rapid In Vitro Multiplication:

In cases where somatic embryogenesis is not feasible or validated, rapid multiplication systems using meristematic tissues offer an alternative. Although this method doesn't achieve the same level of homozygosity or chimera-free plants as somatic embryogenesis, repeated cycles of regeneration and subculture help to segregate chimeras. A notable success using this method is the development of the mutant banana cultivar 'Novaria', through shoot tip irradiation and subsequent in vitro multiplication (Mba et al., 2013).

8.4 Molecular Biology Strategies:

Molecular tools enhance the precision and efficiency of mutation detection and selection. Techniques like TILLING (Targeting Induced Local Lesions IN Genomes) allow high-throughput detection of mutations in specific genes, reducing reliance on time-consuming field trials. Though these tools may not always confirm the phenotypic expression of a mutation, they greatly streamline the screening process. Additionally, various molecular markers are routinely used to identify and track mutations and genetic variation in germplasm collections (Jain et al., 2021).

IX. BIOTIC STRESS RESISTANCE: A SUCCESSFUL EXAMPLE

One of the early and successful applications of mutation breeding in fruit crops was in Japanese pear (Pyrus serotina var. culta). In the 1960s, Japanese scientists used chronic gamma irradiation on the highly susceptible cultivar 'Nijisseiki' to develop a resistant mutant 'Gold-Nijisseiki' against black spot disease caused by *Alternaria alternata*. Following this, other susceptible cultivars such as 'Shinsui' and 'Osa-Nijisseiki' were also improved via mutation breeding, leading to resistant lines 'Kotobuki-Shinsui' and 'Osa-Gold'. Notably, 'Osa-Gold' is self-compatible, removing the requirement for additional pollinizer trees in orchards—a major commercial advantage (Pathirana, 2011). Moreover, mutation breeding has contributed to the development of salinity and drought-tolerant lines in citrus, addressing major abiotic stresses in fruit production systems.

X. ACHIEVEMENTS OF MUTATION BREEDING

Mutation breeding has proven to be a powerful tool in the genetic improvement of fruit crops, leading to the development of several commercially valuable traits. Noteworthy improvements include disease resistance in Japanese pear and peach, seedlessness in citrus and guava, dwarf plant types in papaya and pomegranate, and early fruiting in crops like banana, apricot, jujube, plum, and apple. These traits significantly enhance the agronomic and commercial value of cultivars. The success of mutation breeding is closely linked to the careful selection of appropriate technologies for inducing mutations and selecting desirable mutants. With the integration of modern plant tissue culture and molecular biology techniques into conventional breeding frameworks, the generation of new genetic variants has become more targeted and efficient. The application of mutation techniques has introduced vast genetic diversity, contributing not only to plant breeding but also to the fields of genetics and genomics. Globally, the widespread implementation of mutation breeding has led to the release of thousands of improved varieties across a broad range of crops, translating into billions of dollars in added agricultural revenue. The FAO/IAEA's Mutant Variety Database (MVD) maintains detailed records of officially released mutant cultivars worldwide. These records include data on the type and dose of mutagen used, traits improved, and where available, related agronomic information. According to this database, as of December 2016, a total of 3,246 mutant varieties had been officially released. A mutant variety, as recognized in the MVD, may result from the direct use of a line developed via chemical or physical mutagenesis, somaclonal variation, or activation of endogenous transposable elements; or from its indirect use as a parent in cross-breeding programs. In some cases, genes from wild species have been introduced into cultivated genomes through radiation-facilitated translocations (Viana et al., 2019).

XI. NEW TECHNIQUES FOR MUTATION INDUCTION, SCREENING, AND UTILIZATION

Recent advances have greatly expanded the scope and accuracy of mutation breeding. Novel methods for inducing mutations now include exposure to space flight conditions, high-energy ion irradiation, and the activation of transposable elements. Additionally, techniques such as site-directed mutagenesis using restriction endonucleases and homologous recombination have enabled more precise genetic modifications. These innovations are supported by molecular approaches that improve the screening and utilization of mutant lines. A major breakthrough in this area is the development of TILLING (Targeting Induced Local Lesions IN Genomes), a high-throughput and cost-effective reverse genetics method that allows for the identification of mutations at the DNA level. A related technique, EcoTILLING, has been adapted for detecting natural nucleotide polymorphisms. The use of DNA markers tightly linked to desired traits has further enhanced the efficiency of selection through marker-assisted breeding. These molecular tools are essential for tracking and confirming mutations and reducing the need for large-scale field trials. Ultimately, combining mutation induction with gene sequencing and molecular marker technologies opens up new possibilities for developing cultivars with improved nutrient uptake, enhanced root systems, and tolerance to abiotic and biotic stresses. This will be critical in advancing sustainable agriculture in the face of climate variability and resource constraints (Oladosu et al., 2016; Ma et al., 2021).

XII. PRACTICAL CONSIDERATIONS IN INDUCED MUTAGENESIS

Achieving success in mutation breeding requires careful attention to technical parameters and biological variables. The dose of a mutagen that produces the highest frequency of desirable mutations with the least collateral damage is considered optimal. For physical mutagens such as gamma rays or ion beams, this is typically determined by conducting radio sensitivity tests and estimating the lethal dose for 50% of the treated population (LD_{50}). In many fruit crops, LD_{50} values have been standardized under in vitro conditions to guide effective treatment protocols. For chemical mutagens, several factors influence the outcome, including the freshness and stability of the solution, concentration of the mutagen, exposure time, treatment temperature, and the condition of the target tissue. Other influential parameters include the presence of catalytic ions such as Cu^{2+} and Zn^{2+}, pH (commonly maintained near 7.0), and pre- and post-treatment handling methods. Similarly, in the case of physical mutagens, environmental conditions such as oxygen levels, moisture content, and temperature, as well as the physical state of the tissue (presence of dust, fibers, or microbial contaminants), can affect mutation efficiency and plant survival. In general, while the specific steps and responses may vary between sexually and asexually propagated crops, certain fundamental principles apply across systems. These include a clear understanding of the genetic background and reproductive biology of the target crop, the selection of appropriate propagation materials, knowledge of chromosome number and genetic lineage, careful choice of mutagen and dose, and the availability of infrastructure for screening and selection. It is also essential to employ effective methods for detecting and separating stable mutants from chimeric tissues. A strategic combination of these considerations enhances the reliability and success rate of induced mutagenesis in fruit crop improvement programs (Roychowdhury and Tah, 2013).

XIII. CONCLUSION

Mutation breeding has emerged as a powerful and precise tool for the genetic improvement of fruit crops, especially where, conventional breeding faces biological and logistical limitations. Over the decades, its application has led to the development of improved cultivars with traits such as disease resistance, dwarfism, seedlessness, and early maturity. The integration of modern biotechnological advancements—like in vitro mutagenesis, molecular markers, and TILLING—has significantly enhanced the efficiency and accuracy of mutant selection. Additionally, innovative screening techniques and strategic use of tissue culture have overcome major challenges such as chimerism and low mutation efficiency in vegetatively propagated crops. As climate change and resource constraints demand more resilient and productive cultivars, mutation breeding will continue to play a crucial role in developing stress-tolerant, high-yielding, and consumer-preferred fruit varieties. The future lies in combining classical mutagenesis with genomics, precision breeding tools, and sustainable agricultural practices to ensure long-term food and nutritional security.

REFERENCES

[1] Ben-Amar, A., Daldoul, S., Reustle, G. M., Krczal, G., & Mliki, A. (2016). Reverse genetics and high throughput sequencing methodologies for plant functional genomics. *Current Genomics, 17*(6), 460–475.

[2] Gelvin, S. B. (2017). Integration of *Agrobacterium* T-DNA into the plant genome. *Annual Review of Genetics, 51*(1), 195–217.

[3] Jain, S. M. (2002). A review of induction of mutations in fruits of tropical and subtropical regions. *Acta Horticulturae, 575*, 295–302.

[4] Kodym, A., & Afza, R. (2003). Physical and chemical mutagenesis. In *Plant functional genomics* (pp. 189–203). Humana Press.

[5] Lu, B., Winnall, S., Cross, W., & Barnes, C. P. (2025). Cell-cycle dependent DNA repair and replication unifies patterns of chromosome instability. *Nature Communications, 16*(1), 3033.

[6] Ma, L., Kong, F., Sun, K., Wang, T., & Guo, T. (2021). From classical radiation to modern radiation: Past, present, and future of radiation mutation breeding. *Frontiers in Public Health, 9*, 768071.

[7] Nei, M. (2007). The new mutation theory of phenotypic evolution. *Proceedings of the National Academy of Sciences, 104*(30), 12235–12242.

[8] Oladosu, Y., Rafii, M. Y., Abdullah, N., Hussin, G., Ramli, A., Rahim, H. A., Miah, G., & Usman, M. (2016). Principle and application of plant mutagenesis in crop improvement: A review. *Biotechnology & Biotechnological Equipment, 30*(1), 1–16.

[9] Pathirana, R. (2011). Plant mutation breeding in agriculture. *CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources, 6*(032), 1–20. https://doi.org/10.1079/PAVSNNR20116032

[10] Roychowdhury, R., & Tah, J. (2013). Mutagenesis—A potential approach for crop improvement. In *Crop improvement: New approaches and modern techniques* (pp. 149–187). Springer.

[11] Rugini, E., Bashir, M. A., Cristofori, V., Ruggiero, B., & Silvestri, C. (2020). A review of genetic improvement of main fruit trees through modern biotechnological tools and considerations of the cultivation and research of the engineered plant restrictions. *Pakistan Journal of Agricultural Sciences, 57*(1).

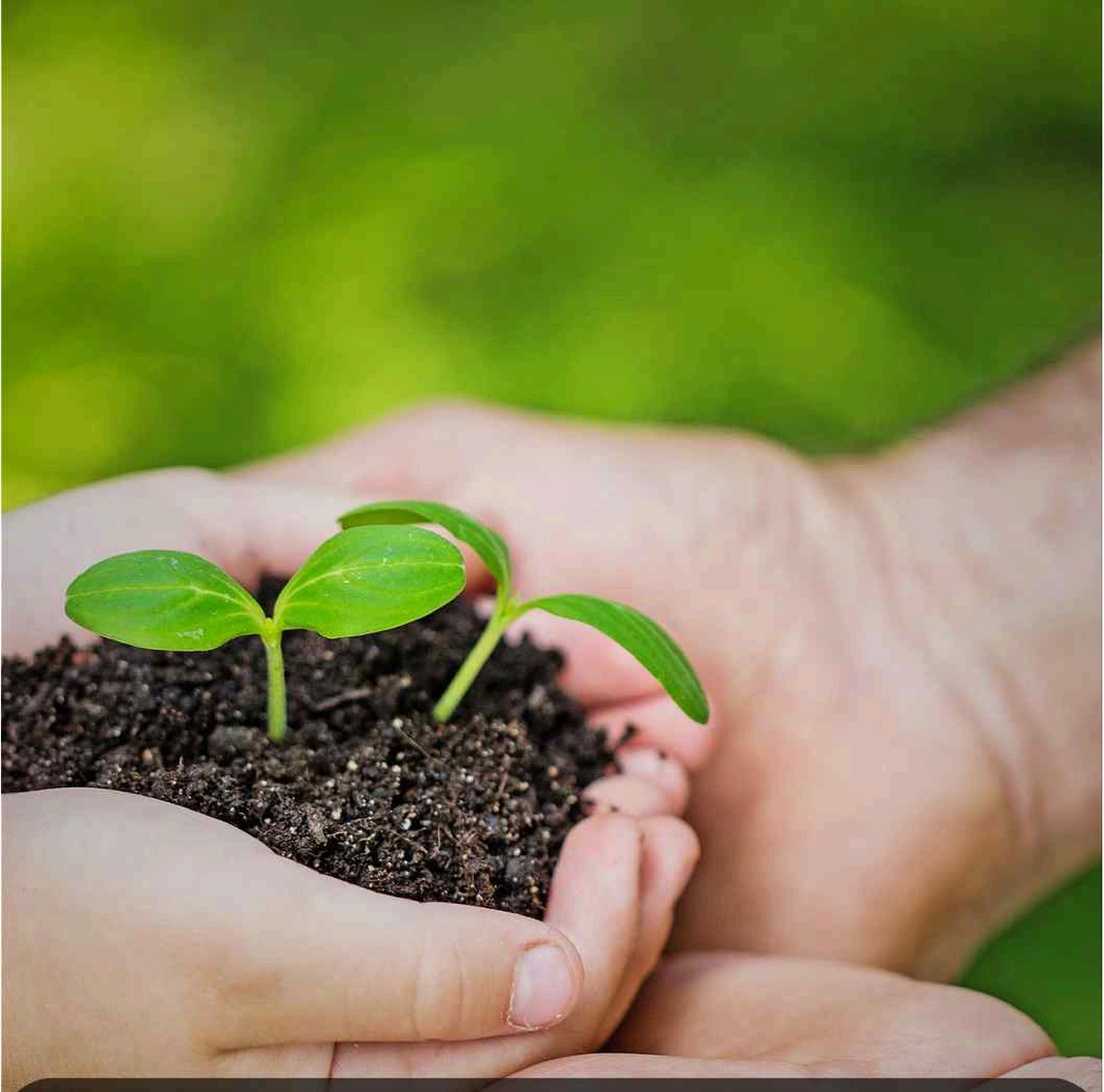
[12] Sattar, M. N., Iqbal, Z., Al-Khayri, J. M., & Jain, S. M. (2021). Induced genetic variations in fruit trees using new breeding tools: Food security and climate resilience. *Plants, 10*(7), 1347.

[13] Singh, D., Chaudhary, P., Taunk, J., Singh, C. K., Chinnusamy, V., Sevanthi, A. M., Singh, V. J., & Pal, M. (2024). Targeting induced local lesions in genomes (TILLING): Advances and opportunities for fast-tracking crop breeding. *Critical Reviews in Biotechnology, 44*(5), 817–836.

[14] Theunissen, B. (1998). The scientific and social context of Hugo de Vries' *Mutationstheorie*. *Acta Botanica Neerlandica, 47*(4), 475–490.

[15] Viana, V. E., Pegoraro, C., Busanello, C., & Costa de Oliveira, A. (2019). Mutagenesis in rice: The basis for breeding a new super plant. *Frontiers in Plant Science, 10*, 1326.

[16] Zhang, Z., & Gerstein, M. (2003). Patterns of nucleotide substitution, insertion and deletion in the human genome inferred from pseudogenes. *Nucleic Acids Research, 31*(18), 5338–5348.



AD Publications

www.ijoear.com

info@ijoear.com | info.ijoear@gmail.com