REDVET - Revista electrónica de Veterinaria - ISSN 1695-7504
Vol 25, No. 1S (2024)
http://www.veterinaria.org
Article Received: Revised: Accepted:

Impact Of Agrochemicals On Global Climate Change & Sustainable Human Health

Deepmala Babasaheb Tambe[1], B.Hemavathi [2], S.Anuradha [3], N. Siddulu [4] , Marina Albuquerque[5], Balaraju Parshaveni [6], Devidas Narhar Patil[7*]

[1*]Associate Professor, Department of Botany, Savitribai Phule Pune University, Pune.
[2]Assistant Professor in Zoology, Department of Bioscience and Sericulture, Sri Padmavati Mahila Viswavidyalayam,Tirupati, Andhra Pradesh
[3]Associate Professor of Botany, Government Degree College, Chevella -Rangareddy Dist TS
[4]Assistant Professor of Botany, Tara Government College (A), Sangareddy, T.S.
[5] Associate Professor of Microbiology, HOD, Government College of Arts, Science & Commerce, Khandola, Goa
[6]Assistant Professor, SRR Govt Arts and Science College (A) Karimnagar, Telangana, Satavahana University 505001
[7]Associate Professor and Head, Department of Botany, Bharatiya Jain Sanghatana's Arts Science and Commerce College, Wagholi, Pune.

***Corresponding Author:-** Devidas Narhar Patil:
***Email:-** dnpatil2030@gmail.com

Abstract
The application of agrochemicals represents a wide range of chemical entities applied in agriculture toward enhancing crop production and pest control. This has important implications for both global climate change and human health sustainability. Article focusing on exploring the impact of some bioactive compounds derived from endophytic fungi metabolites, viewing their potential as being antioxidants, antifungals, antibacterials, and anticancer agents. Endophytic fungi are fungi that reside within plant tissue but do not cause damage, while it is their metabolites, notably alkaloids, terpenes, quinolones, and other secondary metabolites, which present an array of biological activities for agricultural and pharmaceutical applications. Extractive methods include those techniques that identify metabolites either from fungal cultures or plants that have endophytes, succeeded by purification to obtain compounds at high purity levels for further studies and applications. Characterization methods describe the chemical structures and properties of those compounds of importance in understanding their bioactivities and potential uses; among these are the spectroscopic techniques of NMR and mass spectrometry, which describe.
The paper seeks to discuss the dual roles of agrochemicals in relation to environmental dynamics and human welfare. On the one hand, potential benefits to agriculture could include increased productivity, security of food availability, and economic growth. On the other, concern exists over far-reaching environmental pollution, disruption of ecosystems, and exposure of humans to residues, which pose health threats. Against the background of emerging climatic challenges stands the imperativeness of knowledge on the sustainable use of agrochemicals. With respect to agriculture, the reduced use of synthetic chemicals through the exploitation of endophytic fungal bioactives looks forward to reduce environmental impacts, improving human health with safer alternatives

Keywords: Agrochemicals, global climate change, human health, bioactives, antioxidants, antifungal, antibacterial, endophytes, alkaloids, terpenes, quinolones.

Introduction to Agrochemicals and Their Impacts

Definition and Types of Agrochemicals

The utilization of agrochemicals in agriculture has been practiced with the purpose of increasing crop production, protecting plants from pests and diseases, and improving soil fertility. They refer to a wide range of products, including the following:
1. Pesticides: These are chemicals used against pests such as insects, weeds, fungi, or rodents.
2. Fertilizers: These are substances that supply plants with nutrition for their growth. Organic fertilizers come from organic sources, while synthetic fertilizers are made through chemical synthesis.
3. Soil Amendments: Added into the field soil to enhance its properties, it includes pH adjusters, lime, sulfur, or other soil conditioners.
4. Plant Growth Regulators: Chemicals that alter plant growth, generally focused on flowering, fruiting, and root development.
5. Adjuvants: Added ingredients in agrochemical formulations to increase their efficiency, such as surfactants, spreaders, and stickers.

REDVET - Revista electrónica de Veterinaria - ISSN 1695-7504
Vol 25, No. 1S (2024)
http://www.veterinaria.org
Article Received: Revised: Accepted:

Importance in Agriculture and Global Food Production

Agrochemicals are an important ingredient in the process called modern agriculture. Ideally, they play a critical role in contributing to global food production and security. Their principal advantages are:

1. Increased Crop Yields: Agrochemicals increase crop productivity by supplying the crops with required nutrients and also protecting them from pests and diseases. This is quite important in ensuring sufficient food for the increasing human population.
2. Superior Quality Crops: Fertilizers and plant growth promoters also improve the nutrient, aesthetic, and storage value of agricultural crops.
3. Pest and Disease Management: Pesticides keep pest populations under control so that they do not cause crop loss by infestation or disease and provide stable food supplies.
4. Efficient Land Use: With increased productivity per unit area, agrochemicals make for better utilization of arable land and thus help retain natural habitats and ecosystems with their biodiversity.
5. Economic Benefits: Greater yields with higher quality will mean greater incomes for farmers, which are both appropriate for sustaining rural economies and livelihhoods.

Environmental and Health Risks Associated with the Use of Agrochemicals

Despite the several advantages, the use of agrochemicals is linked to some environmental and health risks associated with their use. These include:

1. Environmental Pollution:
   - Water Contamination: Agricultural field runoff can carry agrochemicals into water bodies, contaminating sources of drinking water and causing harm to aquatic ecosystems.
   - Soil Degradation: The overly intensive application of chemical fertilizers can acidify the soil, lower its organic matter content, impact the structure of microbial communities, and hence reduce fertility over some time (Wei et al., 2024).
   - Air Pollution: Pesticides are a source of volatile organic compound emissions that add to air pollution and thus affect the quality of the air and human health.
2. Non-Target Species Injury: Pesticides can unintentionally affect beneficial insects, such as pollinators, wildlife, and plants non-targeted, which may lead to the loss of biodiversity in plants and animals and a requirement for imbalance in ecosystem functions.
3. Human Health Risks:

a. Acute Exposure: The acute exposure occurs when a person makes contact directly with agrochemicals during application. According to Sathish Kumar et al. (2024), many acute health issues, including skin, respiratory diseases, and poisoning, occur to people due to agrochemicals.

Chronic Exposure: The low level and long-term exposure to agrochemicals has been shown to have links to serious health conditions, including cancer, endocrine disruption, and neurological disorders.

Residues in Food: Intake of residues in food due to pesticides can be hazardous to health, especially in children and pregnant women.

Bioactive Compounds from Endophytic Fungi

Overview of the Endophytic Fungi and Their Symbiotic Relationship with Plants

Endophytic fungi are microorganisms that live within plant tissues without causing apparent harm to them. The fungi coexist symbiotically in the sense that both the fungi and the host plants benefit from this association. They colonize the inner tissues of leaves, stems, and roots and pay the host by keeping them safe from environmental stressors and supplying them with the required food through several advantages. These advantages include growth promoting, heightening of resistance against pests and diseases, and tolerance to biotic stresses in the environmental cue: drought and salinity.

Endophytic fungi are very pervasive and are found to occur in almost all plant species. They are also very important in plant health and function of ecosystems. Even diversity in the array of bioactive compounds produced makes them an important focal point for research in agriculture and medicine.

Types of Bioactive Compounds Produced by Endophytic Fungi

Basically, various species of endophytic fungi produce different types of bioactive compounds, which are grouped under a few broad categories. Some of them are as follows:

1. Alkaloids: These are nitrogen-containing compounds; many of which have strong pharmacological effects. Vinblastine and vincristine are two examples described in the literature against certain chemotherapy-treated cancers.
2. Terpenes: One of the larger classes of organic compounds, terpenes are formed from five-carbon isoprene units. They exhibit wide biological activities, such as antimicrobial, anti-inflammatory, and anticancer properties. Siddiqui et al. (2024)
3. Quinolones: Such aromatic organic compounds have a wide spectrum of biological activities that include antibacterial and anticancer effects.

REDVET - Revista electrónica de Veterinaria - ISSN 1695-7504
Vol 25, No. 1S (2024)
http://www.veterinaria.org
Article Received: Revised: Accepted:

4. Polyketides: This constitutes a very broad class of secondary metabolites with a number of biological activities, including antibiotic, antifungal, and anticancer activities.
5. Phenolic Compounds: Characterised by the presence of phenol groups, known to have antioxidant properties.
6. Peptides: Small chains of amino acids, which exert antimicrobial and antiviral activities, along with anti-cancer properties.

Biological Activities of Bioactives and their Potential Applications

The endophytic fungal-derived bioactive compounds exert a broad spectrum of biological activities that enables them for various uses:
1. Antioxidant Activity: phenolic compounds, flavonoids, or other bioactives scavenge free radicals, hence protecting the cells from any oxidative stress and possible damages. This does food preservation and health supplements. Bjouyahya et al.,2024.
2. Antifungal and Antibacterial Activities: the growth of pathogenic fungi and quinolones restrain bacteria, which can accordingly be applied in agriculture fungicides and antibiotics.
3. Antitumor Activity: Some of the alkaloid and polyketide compounds display cytotoxic effects on cancer cells; thus, they form leads for the discovery of new antitumor chemotherapeutic agents.
4. Anti-inflammatory Activity: Some bioactives have been identified that can bring down inflammatory conditions that can be used in treating inflammatory diseases and also for the development of anti-inflammatory drugs.
5. Promotion of Plant Growth: Several hormones and other compounds can be produced by endophytic fungi that can enhance plant growth and make plants more resistant, which can find application in sustainable agriculture. Extraction, Purification and Characterization Processes.

Methods of Extraction of Bioactive Compounds from Endophytic Fungi

Extraction of bioactive compounds from endophytic fungi involves steps for the isolation and concentration of metabolites of interest. It consists of the following steps:
1. Cultivation of Fungi: The endophytic fungus is cultivated for sufficient biomass in controlled conditions. This may be conducted on solid or liquid media, depending on the fungus and targeted compounds, such as described by Ling et al. (2024).
2. Extraction: Treatment of the fungal biomass/culture medium for the extraction of bioactive compounds with different solvents like methanol, ethanol, acetone, and ethyl acetate. This is done with techniques such as maceration, Soxhlet extraction, and ultrasound-assisted extraction for maximum yield.
3. Solvent Partitioning : Extracts are often processed for solvent partitioning. This will separate the compounds according to their polarity, hence making subsequent purification easier.

Techniques of Purification and Isolation of Bioactives

Once extracted, bioactive compounds have to be purified in order to isolate them in their active form. Purification techniques include chromatography techniques such as column chromatography, high-performance liquid chromatography, and gas chromatography. Key aspects are:
1. Chromatography: Purification techniques follow extraction, where the use of several chromatography kinds is included, notably:
o Column Chromatography: Separates compounds on the basis of differential adsorption to a stationary phase.
o High-Performance Liquid Chromatography: Used to separate and quantify compounds at high resolution.
o Gas Chromatography: Specifically for volatile compounds.
2. Crystallization: This can be used in the purification of most compounds from a solution upon crystallization, especially alkaloids and other active ingredients in crystalline form.
3. Distillation: Used to purify volatile compounds based on their differences in boiling points.

Techniques for Purification and Isolation of Bioactives

Technique	Principle	Applications	Advantages	Disadvantages
Column Chromatography	Separation based on differential adsorption to a stationary phase	General separation of compounds from complex mixtures	Simple setup, inexpensive, suitable for large samples	Time-consuming, less efficient for complex mixtures
High-Performance Liquid Chromatography (HPLC)	Separation based on differential partitioning between a liquid mobile phase and a stationary phase	High-resolution separation and quantification of compounds	High resolution, reproducible, automated	Expensive equipment, requires maintenance
Gas Chromatography (GC)	Separation based on differences in volatility and interaction with a stationary phase	Separation and analysis of volatile compounds	High resolution, fast analysis, suitable for volatile compounds	Limited to volatile and thermally stable compounds

REDVET - Revista electrónica de Veterinaria - ISSN 1695-7504
Vol 25, No. 1S (2024)
http://www.veterinaria.org
Article Received: Revised: Accepted:

Crystallization	Inducing crystallization from a solution to purify compounds	Purification of alkaloids and other crystalline substances	High purity, simple method, cost-effective	Not suitable for all compounds, may require multiple steps
Distillation	Separation based on differences in boiling points	Purification of volatile compounds	Efficient for volatile substances, simple setup	Not suitable for non-volatile or thermally unstable compounds

Characterization Methods to Analyze Chemical Structures and Properties

Technique	**Principle**	**Applications**	**Advantages**	**Disadvantages**
Nuclear Magnetic Resonance (NMR) Spectroscopy	Provides detailed information on molecular structure, functional groups, and dynamics through nuclear spin interactions in a magnetic field	Structural elucidation, dynamics, functional group identification	Detailed structural information, non-destructive	Requires large amounts of sample, expensive equipment
Mass Spectrometry (MS)	Determines molecular weight and structure through ionization and mass-to-charge ratio analysis	Molecular weight determination, structural elucidation	High sensitivity, specificity, suitable for complex mixtures	Requires ionization, can be destructive
Infrared (IR) Spectroscopy	Identifies functional groups based on absorption of infrared light corresponding to vibrational transitions	Functional group identification, molecular structure analysis	Fast, non-destructive, requires small sample amounts	Limited structural information, not suitable for all compounds
Ultraviolet-Visible (UV-Vis) Spectroscopy	Analyzes conjugated systems and quantifies concentrations based on absorption of UV and visible light	Quantification of compounds, analysis of conjugated systems	Simple, fast, suitable for quantitative analysis	Limited to chromophores, less structural information
Chromatography-Mass Spectrometry (LC-MS/GC-MS)	Combines separation and mass analysis for comprehensive compound identification	Comprehensive analysis, separation, and identification of compounds	High sensitivity, high resolution, suitable for complex mixtures	Expensive equipment, requires skilled operation
X-ray Crystallography	Provides three-dimensional structure of crystalline compounds at atomic resolution through X-ray diffraction	Structural determination of crystalline compounds	High-resolution 3D structures, precise atomic positions	Requires high-quality crystals, time-con

Characterization Techniques of Bioactive Compounds in Determination of Their Chemical Structures and Properties

The characterization of bioactive compounds is essential to establish their chemical structure in terms of molecular size and properties. The techniques used in this method are as follows:

1. Spectroscopic Techniques

o Nuclear Magnetic Resonance, NMR Spectroscopy: It details the molecular structure and functional groups and distinguishes the dynamics of molecules.

o Mass Spectrometry, MS: Molecular determination of weight is used in determining the compound's structure.

o Infrared, IR Spectroscopy: This technique determines the functional groups based on the.

o Ultraviolet-Visible Spectroscopy: Useful for the study of conjugated systems and the determination of concentration quantitatively.

2. вoг-Chromatography-Mass Spectrometry (LC-MS/GC-MS): It links separation to mass analysis to provide full identification of compounds.
3. tX-ray Crystallography: Provides a three-dimensional structure of crystalline compounds at atomic resolution.

Biological Activities and Applications

Antioxidant Properties and Its Applications in Agriculture and Health

According to Asomadu et al. (2024), the antioxidant compounds generated by endophytic fungi are responsible for scavenging free radicals. The presence of such free radicals leads to a reduction in oxidative stress and cell damage. Such activities render central to aspects of agriculture and health:

a. Plant Health: The antioxidants, having been incorporated in the plant, help the plant to cope against several environmental stressors such as drought, harsh temperatures, and pollution that impinge directly on the tolerance of plants, therefore enhancing plant productivity.

o Preservation after Harvest: Antioxidants can serve the purpose of extending the life of fruits, vegetables, and other perishable goods by preventing them from oxidative degradation.

o Protection from Diseases: Antioxidants play a critical role in the body towards protecting the human cells from oxidative stresses responsible of causes chronic diseases such as cancer, cardiovascular, and neurogenerative disorders among many others (Muscolo et al.,2024).

REDVET - Revista electrónica de Veterinaria - ISSN 1695-7504
Vol 25, No. 1S (2024)
http://www.veterinaria.org
Article Received: Revised: Accepted:

o Nutritional Supplements: Natural antioxidants from endophytic fungi may get their way into dietary supplements to improve general health and well-being\tmarketing products.

Antifungal and Antibacterial Activities for Crop Protection and Pharmaceutical Use

Endophytic fungi have been reported to produce variously bioactive compounds displaying potent antifungal and antibacterial activities with immense applications against plant and human pathogens in agriculture and medicine, respectively. These include:

1. In Agriculture:

a. Crop Protection: The natural antifungal and antibacterial agents can be explored as bio-pesticides against pathogenic fungi and bacteria on crops, hence reducing the quantity of synthetic pesticides applied and the consequent environmental effects.

- Soil Health: They carry out activities that influence soil health by regulating soil-borne pathogens as well as promoting the development and progress of beneficial microbial communities.

2. In Pharmaceuticals:

- Controlling Infection: Antifungal and antibacterial bioactive from endophytes offer the potential and opportunity by the discovery of novel antibiotics and new antifungal drugs for combating the threat of antimicrobial resistance.
- TopicalApplications: Bioactive compounds can be woven into the cream, ointment, and other topical medication for skin infections or wounds healing.

Anticancer Potential Aand Other Therapeutic Applications of Bioactives

In this regard, bioactive compounds from endophytic fungi have exhibited various therapeutic roles, with anticancer properties among them. These include the following:

1. Anticancer Properties:

Cytotoxicity: Alkaloids and polyketides were found to exhibit cytotoxic properties against numerous lines of human cancer cells by the induction of programmed cell death and the suppression of tumor growth by Chen et al.,2024.

Drug Development: These natural products might also form lead compounds to demonstrate novel chemotherapeutic drugs whose side effects could be significantly reduced when compared to the already existing standard drugs.

2. Other Therapeutic Roles:

- Anti-Inflammatory Effects

These anti-inflammatory bioactives could be used for the development of treatments against inflammatory diseases like arthritis and inflammatory bowel disease.

- Antiviral Activity

Some metabolites have depicted antiviral activity against viral pathogens, which has established new routes for the development of different antiviral drugs.

- Neuroprotective Effects

Some of the compounds could be neuroprotective from diseases like neurodegenerative diseases by preventing the oxidative stress and inflammation of neural tissues.

Environmental Dynamics and Sustainability

Effects of Agrochemicals on Global Climate Change

Agrochemicals are synthetic fertilizers and pesticides; they have huge effects to world climate change:

1. Greenhouse gas emission:

a. Use of synthetic fertilizers in their making and application adds to the emission of CO_2, N_2O, and CH_4, greenhouse gases.

a. Production of pesticides releases into the air CO_2 and other polluting gases.

2. Pollution of soil and water:

- Runoff and Leaching: Agrochemicals can cause runoff and leaching when in excess amounts, thus contaminating water bodies which in turn, affects aquatic ecosystems (Sathish Kumar et al.,2024).
- Soil Health: Continuous use of agrochemical/sub lethal quantities of agrochemicals over an extended period may seriously affect soil health and lead to a decrease in the potential of the soil to sequester carbon and affect soil biodiversity.

Role of Bioactive Compounds in Sustainable Agricultural Practices

Bioactive compounds from endophytic fungi can be applied in sustainable agriculture for:

1. Biopesticides: Natural antifungal and antibacterial chemicals can be applied against fungal and bacterial activities, reducing the chances of environmental pollution and conserving other synergistic organisms.

2. Biofertilizers: Endophytic fungi have been viewed to decrease the application of chemical fertilizer in agriculture as they improve the growth of the plants and enhance nutrient uptake from soil.

REDVET - Revista electrónica de Veterinaria - ISSN 1695-7504
Vol 25, No. 1S (2024)
http://www.veterinaria.org
Article Received: Revised: Accepted:

3. Integrated Pest Management: Bioactives can be integrated into IPM strategies that consider a dynamic mix of biological control, cultural practices, and reduced use of synthetic chemicals in an environmentally sustainable manner for the management of pests.

Case Studies/Examples of Sustainable Use of Agrochemicals
There are several case studies, which points towards the success of bioactives in the field of sustainable agriculture.
1. Trichoderma Species in Disease Control: The endophytic fungi Trichoderma spp. have been utilized for controlling the incidence of soil-borne diseases in major crop plants such as tomatoes and cucumbers, so as to reduce the need or usage of chemical fungicides.
2. Pseudomonas Fluorescens as Biopesticide: The endophytic bacterium Pseudomonas fluorescens has been used on plants like rice and wheat as a biopesticide for the control of plant pathogens in order to increase crop yields and promote soil health.
3. Neem-Based Bioinsecticides: Azadirachta indica derivate bioinsecticide has been used in flirting with insecticide control in different crops vying a substitute for chemical insecticide as a cheap, environment-friendly measure towards sustainability.
Problems and Prospects
Environmental and Health Problems Linked with Agrochemicals
With such a massive use of agrochemicals, various environmental and health concerns and problems are evoking, which include:
1. Environmental Problems:
o Ecosystem Imbalance: Agrochemicals may be potentially hazardous to non-target forms of biota, including beneficial insect and bird species, as well as aquatic life, causes biodiversity reduction, and an imbalanced ecosystem.
o Water Contamination: Runoff and leaching of agrochemicals lead to water contamination sources of drinking water. Living organisms in water courses and accordingly aquatic ecosystem disturbance.
o Soil Degradation: exuberant use of chemical fertilizers and pesticides bring about the degradation of soil structure and fertility, affecting microbial diversity, soil erosion, and ultimately leads to reduced soil fertility.
2. Health Problems :
o Acute Toxicity: Direct contact or exposure to agrochemicals may cause acute health hazard symptoms like skin and eye irritation, respiratory problem in human being apart from food poisoning.
o Chronic Health Effects: Even relatively shorter duration of exposure to low amounts of agrochemicals may cause chronic diseases such as different forms of cancer, hormonal disruption, problems in reproduction, and alteration in the neurological system. (Ansari et al.,2024).
o Food Safety: Residues of these pesticides and other agrochemicals in food products pose dangers to consumers, especially the vulnerable groups, such as children and pregnant women .

Regulatory Considerations and Advisory by Good Practices
The problems surrounding use of agrochemicals therefore require strong regulatory requirements by sustainable practice:
1. Mandatory Regulatory Requirements:
o Safety Standards: Developing and implementing safety standards for the production and use, and the residue level of agrochemicals to protect human health and the environment.
o Monitoring and Compliance: Design monitoring programs as a tool for checking compliance with regulations and tracking the environments and health effects emanating from agrochemicals use.
o Risk Assessment: Comprehensive risk assessment of both new and existing agrochemicals is performed to assess their potential effects and provide a decision tool for regulators.
2. Sustainable Practices:
o Integrated Pest Management (IPM): Fostering the implementation of IPM approach which integrates biological control and cultural practices with minimum usage of synthetic chemicals for managing pests.
o Organic Farming: Promotion of organic farming methods that exclude synthetic agrochemicals and utilize naturally available material, such as compost, biopesticides, and crop rotation.
o Precision Agriculture: Using precision agriculture technologies in the judicious use of agrochemicals with maximum efficiency to minimize wastage and therefore lower the environmental burden.

Future Research Directions and Innovations in Agrochemical Use
Innovations and research are the way to develop alternatives to traditional agrochemicals through sustainable means:
1. Biopesticides and Biofertilizers: Screening, identification, and formulation of bioactive compounds from the endophytic fungi and other microorganisms for effective and eco-friendly pesticides and fertilizers. Kumar et al. (2024) Identification and formulation of available bioactive compounds from the endophytic fungi and other microorganisms into effective and eco-friendly pesticide and fertilizers.

2. Genetic Engineering: To develop crops that have inbuilt resistance to pests and diseases so that there will be no requirement of chemical pesticides.
3. Nanotechnology: Practicable use of nanotechnology in the agrochemicals in order to increase their efficacy and decrease the dosage required mostly for reducing the chances of environmental hazard.
4. Sustainable Production Methods: Develop sustainable methods to use and produce agrochemicals, including the use of resources that can be renewed and clean environmental processes for their manufacture.
5. Interdisciplinary Research: To promote more fully integrated research at the interface between plant science, microbiology, chemistry, and environmental science as a way of addressing the multi-faceted challenges posed by agrochemical use.

Conclusion

Summary of the Two Faces of Agrochemicals in Agriculture and Sustainability

Agrochemicals contribute to agriculture by enhancing crop productivity and increasing food security and, at the same time, adversely affect the environment and human health. Pollution, perturbation of ecosystems, and human health risks are some of the environmental and health concerns raised by the extensive application of the agrochemicals, which rid yields of their crops' quality (Lakhiar et al., 2024).

Importance of Bioactives from Endophytic Fungi as Alternatives

Bioactive compounds from the endophytic fungi offer promise for replacement of the conventional agrochemicals. They are characterized by a wide range of distinct biological activities, which include antioxidant, antifungal, antibacterial, as well as anticancer compounds capable of being exploited for sustainable agriculture and pharmaceutical applications. Their uses in these fields can result in reduced dependence on synthetic chemicals, decreased potential risks to the environment, and safety for humans' health.

Recommendations for Sustainable Agricultural and Health Outcomes

Consequently, the following recommendations are made:
1. Encourage Research and Development: Investment in research towards discovery and development of bioactive compounds from endophytic fungi and other natural sources.
2. Embracing Sustainable Practices: Promoting the use of sustainable agricultural practices inclusive of IPM Organic farming and Precision Agriculture
3. Regulatory Strengthening: Development and stringent implementation of the regulatory framework for agrochemicals to ensure their safe use without harm to human health and the environment.
4. Training Stakeholders: Those to be trained include farmers, policy framers, and the public on benefits of the sustainable practices and risks they are involved with in using the agrochemicals.
5. Create Synergy: Supportive creation of collaboration between the scientists, industry, and governments to develop innovative solutions and exchange best practices in sustainable agriculture.

REFERENCES

1. Ansari, I., El-Kady, M. M., Mahmoud, A. E. D., Arora, C., Verma, A., Rajarathinam, R. K., ... & Mittal, J. (2024). Persistent pesticides: Accumulation, health risk assessment, management and remediation: an overview. *Desalination and Water Treatment*, 100274.
2. Asghar, W., Craven, K. D., Kataoka, R., Mahmood, A., Asghar, N., Raza, T., & Iftikhar, F. (2024). The application of Trichoderma spp., an old but new useful fungus, in sustainable soil health intensification: A comprehensive strategy for addressing challenges. *Plant Stress*, 100455.
3. Asomadu, R. O., Ezeorba, T. P. C., Ezike, T. C., & Uzoechina, J. O. (2024). Exploring the antioxidant potential of endophytic fungi: a review on methods for extraction and quantification of total antioxidant capacity (TAC). *3 Biotech*, *14*(5), 1-18.
4. Bhunjun, C. S., Phukhamsakda, C., Hyde, K. D., McKenzie, E. H., Saxena, R. K., & Li, Q. (2024). Do all fungi have ancestors with endophytic lifestyles?. *Fungal Diversity*, *125*(1), 73-98.
5. Bouyahya, A., Bakrim, S., Aboulaghras, S., El Kadri, K., Aanniz, T., Khalid, A., ... & El Omari, N. (2024). Bioactive compounds from nature: Antioxidants targeting cellular transformation in response to epigenetic perturbations induced by oxidative stress. *Biomedicine & Pharmacotherapy*, *174*, 116432.
6. Chen, Y., Liu, H., Wang, N., Tan, H., & Zhang, W. (2024). Pararorine A, isoindolinone alkaloid from the endophytic fungus Paramyrothecium roridum and its anti-tumor activity. *Fitoterapia*, *175*, 105931.
7. Ghorbani, A., Emamverdian, A., Pehlivan, N., Zargar, M., Razavi, S. M., & Chen, M. (2024). Nano-enabled agrochemicals: mitigating heavy metal toxicity and enhancing crop adaptability for sustainable crop production. *Journal of Nanobiotechnology*, *22*(1), 91.

REDVET - Revista electrónica de Veterinaria - ISSN 1695-7504
Vol 25, No. 1S (2024)
http://www.veterinaria.org
Article Received: Revised: Accepted:

8. Kumar, D., Singh, P. N., Willer, H., Sharma, S. K., Singh, U. B., Lagashetti, A. C., & Husain, R. (2024). Fungal Biofertilizers and Biopesticides and Their Roles in Sustainable Agriculture. In *Applied Mycology for Agriculture and Foods* (pp. 165-216). Apple Academic Press.
9. Lakhiar, I. A., Yan, H., Zhang, J., Wang, G., Deng, S., Bao, R., ... & Wang, X. (2024). Plastic pollution in agriculture as a threat to food security, the ecosystem, and the environment: an overview. *Agronomy*, *14*(3), 548.
10. Lal, J., Swaminathan, R., Meena, A. K., & Nagar, R. (2024). Field efficacy of bio-rational insecticides against major pestiferous insects of cabbage. *International Journal of Pest Management*, *70*(1), 7-13.
11. Ling, L., Feng, L., Li, Y., Yue, R., Wang, Y., & Zhou, Y. (2024). Endophytic Fungi Volatile Organic Compounds as Crucial Biocontrol Agents Used for Controlling Fruit and Vegetable Postharvest Diseases. *Journal of Fungi*, *10*(5), 332.
12. Muscolo, A., Mariateresa, O., Giulio, T., & Mariateresa, R. (2024). Oxidative stress: the role of antioxidant phytochemicals in the prevention and treatment of diseases. *International journal of molecular sciences*, *25*(6), 3264.
13. Oirdi, M. E., Yaseen, M., Farwa, U., Raza, M. A., Farhan, M., Sandhu, Z. A., ... & Nahvi, I. (2024). Crops and people: the dangers and potential benefits of pesticides. *Cogent Food & Agriculture*, *10*(1), 2334096.
14. Sathish Kumar, J. K., Monica, S. S., Vinothkumar, B., Suganthi, A., & Paramasivam, M. (2024). Impact of Pesticide Exposure on Environment and Biodiversity: A Review. *Agricultural Reviews*, *45*(1).
15. Sathish Kumar, J. K., Monica, S. S., Vinothkumar, B., Suganthi, A., & Paramasivam, M. (2024). Impact of Pesticide Exposure on Environment and Biodiversity: A Review. *Agricultural Reviews*, *45*(1).
16. Siddiqui, T., Sharma, V., Khan, M. U., & Gupta, K. (2024). Terpenoids in Essential Oils: chemistry, classification, and potential impact on human health and industry. *Phytomedicine plus*, 100549.
17. Verma, J., Kumar, C., Sharma, M., Shukla, A. C., & Saxena, S. (2024). Exploitation of microbial consortia for formulating biofungicides, biopesticides, and biofertilizers for plant growth promotion. In *Entrepreneurship with Microorganisms* (pp. 227-257). Academic Press.
18. Wei, X., Xie, B., Wan, C., Song, R., Zhong, W., Xin, S., & Song, K. (2024). Enhancing soil health and plant growth through microbial fertilizers: Mechanisms, benefits, and sustainable agricultural practices. *Agronomy*, *14*(3), 609.