CHEMICAL METHODS FOR CONTROLLING PESTS AND DISEASES IN AGRICULTURE: A COMPREHENSIVE REVIEW

Rabia Rehman[1*], Umar Imtiaz[2], Shoaib Rasool[3], Mariam Hameed[4], Daima Hamid[5], Ameena Dilshad[6], Zuhaib Ahmad[3], Huzaifa Saeed[4]

Abstract

Chemical methods have been widely used in agriculture to manage pests and diseases. This review provides a comprehensive overview of the chemical methods employed in agricultural practices for pest and disease control. It discusses the different classes of chemical pesticides, including insecticides, fungicides, and herbicides, and their modes of action. The effectiveness of these pesticides against target pests and diseases, as well as the challenges associated with their use, such as resistance development, environmental impact, and human health concerns, are explored. In the realm of insecticides, the classification based on chemical groups and modes of action is discussed. The review examines commonly used insecticides, their efficacy against various pests, and strategies to mitigate resistance. Similarly, the classification and modes of action of fungicides and herbicides are presented, along with their effectiveness and challenges related to resistance development. The review also addresses the concerns associated with chemical pesticide use. Factors contributing to resistance development in pests and diseases are discussed, along with mechanisms of resistance and strategies to manage it. The environmental impact of pesticide use, including effects on non-target organisms, water quality, soil health, and biodiversity, is examined. Human health concerns related to pesticide exposure are also highlighted, along with regulatory measures and safety precautions. Furthermore, emerging trends and alternative approaches are explored. Integrated Pest Management (IPM) principles, which integrate cultural, biological, and chemical control strategies, are discussed as a means to reduce reliance on chemical methods. The potential of biopesticides, including microbial-based and botanical-based formulations, for sustainable pest and disease control is also examined.

Keywords: chemical methods, pest control, disease control, agriculture, pesticides, insecticides,

[1*]Department of Botany, The Islamia University of Bahawalpur.
[2]Seed Science and technology, University of Agriculture Faisalabad.
[3]Pest Warning & Quality Control of Pesticides, Government of Punjab, Pakistan.
[4]Centre of Agricultural Biochemistry and Biotechnology, University of Agriculture Faisalabad.
[5]Agricultural Biotechnology Division, National Institute for Biotechnology and Genetic Engineering Faisalabad.
[6]Department of Agronomy, University of Agriculture Faisalabad.

***Corresponding Author:** Rabia Rehman
*Department of Botany, The Islamia University of Bahawalpur. Email: rabiawum@gmail.com

DOI: 10.53555/ecb/2024.13.02.14

1. Introduction

Pest and disease control in agriculture is of paramount importance for ensuring food security and sustainable crop production. Chemical methods play a significant role in managing pests and diseases, contributing to increased agricultural productivity. The objectives of this review paper are to provide an overview of the significance of chemical methods in pest and disease control in agriculture and to highlight the various approaches and technologies used in this context.

Chemical control methods, including the use of pesticides, have been instrumental in managing harmful weeds, fungi, bacteria, and insect infestations in agricultural fields (Alengebawy et al., 2021). These methods have allowed agriculture to gain a boost in production by effectively controlling pests, diseases, and weeds (Shimada et al., 2021). However, it is essential to consider the ecological risks and human health implications associated with the use of pesticides and heavy metals in agricultural soil and plants (Alengebawy et al., 2021). Therefore, it is crucial to strike a balance between the benefits of chemical control and its potential adverse effects on the environment and human health.

In addition to chemical methods, integrated pest management (IPM) has emerged as a sustainable and holistic approach for controlling pests in the field, minimizing risks to health and the environment (Poudel et al., 2022). IPM combines ecological, biological, physical, and chemical tactics for pest control, emphasizing the importance of cultural practices, biological control agents, and crop rotation in disease and pest management (Seyi-Amole & Onilude, 2021; , Barzman et al., 2015; , Shawer et al., 2018). Furthermore, precision control technology and application in agricultural pest and disease control have been emphasized, focusing on disease detection and classification methods, as well as the development of control systems (Tang et al., 2023).

Biological control agents, such as microbial bio-control agents and endophytic entomopathogenic fungi, have also gained prominence in integrated pest management, offering sustainable pest management technologies that minimize environmental impact (Dey et al., 2021; , Mantzoukas & Eliopoulos, 2020). Moreover, the role of allelopathy in pest management and crop production has been highlighted, indicating the potential of alternative techniques to improve fruit quality and reduce diseases and insect infestations (Wato, 2020; , Islam et al., 2019).

Furthermore, the use of data-driven technologies, such as the Internet of Things (IoT) applications, has been advocated for precision agriculture, enabling the monitoring and reporting of crop diseases and insect pests based on environmental and weather conditions (Abu et al., 2022; , "Crop Disease and Insect Pest Automatic Monitoring and Reporting System Based on Internet of Things Technology", 2020). This technological advancement provides a better understanding of individual agricultural circumstances, facilitating the timely implementation of pest and disease control measures.

In conclusion, the significance of pest and disease control in agriculture cannot be overstated, and chemical methods, along with integrated pest management strategies and technological advancements, play crucial roles in ensuring sustainable crop production. This review paper aims to provide a comprehensive overview of the various approaches and technologies used in pest and disease control in agriculture, emphasizing the importance of balancing productivity with environmental and human health considerations.

2. Chemical Methods for Pest Control:

2.1. Insecticides:

Insecticides play a crucial role in managing pests that pose a threat to agricultural crops and human health. Understanding the classification of insecticides based on chemical groups and modes of action is essential for effective pest management. The Insecticide Resistance Action Committee (IRAC) has developed a comprehensive mode of action classification scheme, encompassing various chemical groups and biologics used in insecticides and acaricides Sparks et al. (2021). This scheme aids in categorizing insecticides based on their modes of action, allowing for a better understanding of their effectiveness and potential for resistance development.

Commonly used insecticides, such as neonicotinoids, sulfoxaflor, and flupyradifurone, are classified into distinct groups by IRAC, despite their similar modes of action (Siviter & Muth, 2020). These insecticides have been widely employed for their effectiveness in targeting specific pests, such as aphids and other harmful insects, contributing to successful pest control in agricultural settings. Additionally, the development of novel insecticides, such as broflanilide, has provided alternative options for pest management, offering different modes of action to combat resistance issues (Katsuta et al., 2019).

However, the widespread use of insecticides has led to the development of resistance in target pests, posing significant challenges to pest management strategies. Multiple-insecticide resistance in mosquitoes and house flies has been reported, highlighting the urgent need for effective resistance mitigation strategies (Edi et al., 2012; , Shah & Shad, 2019). The limited availability of new classes of insecticides further exacerbates the resistance issue, emphasizing the importance of implementing sustainable resistance management practices (Edi et al., 2012).

To mitigate insecticide resistance, various strategies have been proposed, including the adoption of integrated pest management (IPM) approaches, which combine chemical and non-chemical control tactics to reduce reliance on insecticides (Landwehr, 2021). Additionally, the use of baculoviruses as an alternative to chemical insecticides has shown promise in strengthening resistance management strategies, offering a different mode of action for pest control (Landwehr, 2021). Furthermore, the harmonization of classification schemes for mode of action assignment is crucial for utilizing insecticide mode of action classification in chemical hazard and risk assessment more broadly, aiding in the development of effective resistance management strategies (Kienzler et al., 2017).

In conclusion, understanding the classification of insecticides based on chemical groups and modes of action is essential for effective pest management. Commonly used insecticides have demonstrated effectiveness in targeting specific pests, but the development of resistance poses significant challenges. Implementing sustainable resistance management strategies, such as IPM approaches and the use of alternative modes of action, is crucial for addressing resistance issues and ensuring the continued efficacy of insecticides in pest management.

2.2. Fungicides:

The classification of fungicides based on chemical groups and modes of action is crucial for understanding their efficacy and potential for resistance development. Fungicides are categorized into different groups based on their modes of action, allowing for a comprehensive overview of their effectiveness against various pathogens and application methods. Additionally, the challenges related to fungicide resistance and strategies for managing resistance are essential considerations in sustainable disease management practices.

Commonly used fungicides, such as isoxazoline oxathiopiprolin, have shown promising efficacy due to their novel mode of action, targeting oxysterol binding proteins involved in sterol biosynthesis Hollomon (2015). However, the detection of cross-resistance among different classes of fungicides suggests that the mode of action alone may not be an adequate criterion for determining fungicide mixtures and rotation strategies in agricultural and medical sectors (Yang et al., 2019).

Fungicides play a critical role in managing plant diseases, such as Fusarium head blight and ear rot disease in wheat and maize, respectively. The stability and efficacy of integrating fungicides with cultivar resistance have been demonstrated in managing Fusarium head blight, emphasizing the importance of combining different disease management approaches for effective control (Willyerd et al., 2012;, Masiello et al., 2019). Additionally, the use of fungicides against Alternaria solani in potato fields has highlighted the need to alternate or combine fungicides with different modes of action to avoid or delay resistance development (Odilbekov et al., 2019).

Fungicide resistance poses significant challenges in disease management, particularly in fungal populations affecting crops such as wheat and bell peppers. The development and accumulation of resistance in fungal populations increase the need to identify new chemicals with different modes of action to combat resistance issues effectively (Masiello et al., 2019; , Ramdial et al., 2017). Furthermore, the rapid emergence of fungicide resistance in pathogens, such as Alternaria solani, underscores the urgency of implementing resistance management strategies to preserve the efficacy of fungicides (Mostafanezhad et al., 2021; , Chavan & Borkar, 2020).

To address fungicide resistance, various strategies have been proposed, including the evaluation of biocontrol agents and fungicides against Alternaria leaf spot of spinach, aiming to assess the efficacy of different fungicides at varying concentrations (Jangid et al., 2022). Additionally, the use of epidemiological principles to explain fungicide resistance management strategies has emphasized the importance of mixtures outperforming alternations in managing resistance (Elderfield et al., 2017). Furthermore, the development of resistance management strategies, such as identifying when it is financially beneficial to increase or decrease fungicide dose as resistance develops, is crucial for sustainable disease management practices (Bosch et al., 2017).

In conclusion, the classification of fungicides based on chemical groups and modes of action provides valuable insights into their efficacy against various pathogens and application methods. However, the challenges related to fungicide resistance necessitate the implementation of effective resistance management strategies to ensure the continued efficacy of fungicides in disease management.

2.3 Herbicides:

The classification of herbicides based on chemical groups and modes of action is essential for understanding their efficacy in weed control and for developing effective resistance management strategies. Commonly used herbicides have demonstrated effectiveness in targeting specific weeds, but the development of resistance poses significant challenges. Implementing sustainable resistance management strategies is crucial for addressing resistance issues and ensuring the continued efficacy of herbicides in weed management.

Herbicides are classified into different groups based on their modes of action, allowing for a comprehensive overview of their effectiveness against various weeds and application methods. The Herbicide Resistance Action Committee (HRAC) has developed a mode of action classification chart, which categorizes herbicides into different groups based on their target sites and biochemical processes. This classification aids in understanding the diversity of herbicide modes of action and the potential for resistance development Nagai (2017).

Commonly used herbicides, such as glyphosate and acetolactate synthase (ALS) inhibitors, have been widely employed for their effectiveness in controlling a broad spectrum of weeds in various crops. However, the rapid increase in herbicide-resistant weeds poses a significant challenge to global food security, as it can reduce crop production and cause considerable losses. The over-reliance on herbicides as the main weed management tool in agriculture has selected for herbicide-resistant weed populations, emphasizing the need for diverse weed management strategies (Liu et al., 2020; , Larue et al., 2019; , Dong et al., 2021; , Brunharo & Streisfeld, 2022).

Herbicide resistance development is a major concern, and the detrimental effects of herbicide resistance mutations on plant fitness may lead to fitness costs under particular ecological conditions. The recurrent selection of weed populations or individuals showing enhanced herbicide metabolism by the use of low herbicide doses further exacerbates the resistance issue (Vila-Aiub, 2019; , Küpper et al., 2018). The continuous use of herbicides has led to the evolution of resistance to all major herbicide modes of action worldwide, necessitating the development of effective resistance management strategies (Sen et al., 2022).

To address herbicide resistance, various approaches have been proposed, including the promotion of integrated weed management approaches, responsible use of existing herbicides, and support for herbicide resistance management initiatives. Additionally, the rotational use of herbicides according to their modes of action and the discovery of novel phytotoxic molecules are crucial strategies against weed resistance. Furthermore, the development of enzymes for robust herbicide tolerance traits in crops has shown promise in managing herbicide resistance (Ganie et al., 2020; , Oršolić et al., 2021).

In conclusion, the classification of herbicides based on chemical groups and modes of action provides valuable insights into their efficacy against various weeds and application methods. However, the challenges related to herbicide resistance necessitate the implementation of effective resistance management strategies to ensure the continued efficacy of herbicides in weed management.

3. Challenges and Concerns:

3.1. Resistance Development:

To address the factors contributing to pesticide resistance development in pests and diseases, it is essential to consider various biological, ecological, and operational factors. The development of resistance is influenced by genetic, ecological, and operational factors, including the intensity and frequency of pesticide use, the genetic variability of the target pest populations, and the ecological interactions of pests with other biotic and abiotic factors in the environment Kole et al. (2019), Zytynska et al., 2021; , Savary et al., 2019). Additionally, the indiscriminate use of agro-veterinary pesticides and the practice of agriculture in urban settings have been linked to the rapid expansion of insecticide resistance in malaria vectors, contributing to the global burden of pathogens and pests on major food crops (Rugalema & Mnyone, 2020; , Sonhafouo-Chiana et al., 2022).

The mechanisms of resistance to pesticides involve a range of genetic and physiological adaptations in pests and diseases, including target-site mutations, metabolic detoxification, reduced penetration, and enhanced excretion of pesticides (Hawkins et al., 2018; , Jugulam & Gill, 2017; , S & Thangapandiyan, 2019). These mechanisms contribute to the reduced efficacy of pesticides and pose significant challenges to pest management. To mitigate resistance, strategies such as rotation, combination, and alternative control methods have been proposed. These strategies aim to reduce the selection pressure on pest populations and prolong the efficacy of pesticides.

Rotation of pesticides with different modes of action is a widely recommended strategy to mitigate resistance development. By alternating the use of pesticides with distinct modes of action, the risk of selecting for resistant pest populations is reduced, thereby prolonging the efficacy of pesticides (Hough et al., 2022; , Thia et al., 2022). Additionally, the combination of pesticides with different modes of action has shown promise in managing resistance. By using mixtures of pesticides with complementary modes of action, the likelihood of resistance development in pest populations is minimized (Zytynska et al., 2021;, Lagator et al., 2013). Furthermore, the use of alternative control methods, such as biological control agents, entomopathogenic fungi, and RNA-based biocontrols, offers sustainable approaches to pest management, reducing the reliance on chemical pesticides and mitigating resistance issues (Alhadidi, 2023;, Yeşilayer, 2018).

In conclusion, the development of pesticide resistance in pests and diseases is influenced by a complex interplay of biological, ecological, and operational factors. Understanding the mechanisms of resistance and implementing strategies such as rotation, combination, and alternative control methods are crucial for mitigating resistance and ensuring the continued efficacy of pesticides in pest management.

3.2. Environmental Impact:

The ecological consequences of chemical pesticide use are multifaceted, impacting non-target organisms, water quality, soil health, and biodiversity. Pesticides, while effective in controlling pests and diseases, can have unintended adverse effects on the environment. The impact on non-target organisms, including beneficial insects, birds, and aquatic life, is a significant concern. Pesticides can disrupt food chains, leading to a decline in non-target species and affecting ecosystem balance Guedes et al. (2016), Rwomushana et al., 2017). Furthermore, pesticide residues can contaminate water bodies, posing risks to aquatic organisms and compromising water quality (Passeport et al., 2013; , Chandler et al., 2021). Soil health is also affected, as pesticides can accumulate in the soil, impacting microbial communities, nutrient cycling, and overall soil fertility (Hagstrum & Phillips, 2017; , Cunha et al., 2012). Additionally, the use of pesticides can lead to a reduction in biodiversity, affecting the abundance and diversity of species in agricultural and natural ecosystems (Barzman et al., 2015; , Fahad et al., 2015).

To minimize environmental risks associated with pesticide use, various strategies have been proposed, including the establishment of buffer zones, careful application timing, and integrated pest management (IPM) approaches. Buffer zones, such as vegetated strips along water bodies, can help intercept and remove pesticide residues, reducing the risk of water contamination (Passeport et al., 2013; , Carluer et al., 2017). Careful timing of pesticide application, taking into account factors such as weather conditions and pest life cycles, can minimize off-target effects and reduce environmental exposure (Hagstrum & Phillips, 2017; , Cunha et al., 2012). Integrated pest management (IPM) emphasizes the use of diverse pest control methods, including biological controls, cultural practices, and the judicious use of pesticides, to minimize reliance on chemical control and mitigate environmental impacts (Fahad et al., 2015; , Rahman, 2020). By integrating multiple pest management tactics, IPM aims to reduce the overall use of pesticides while maintaining effective pest control.

In conclusion, the ecological consequences of chemical pesticide use encompass a range of environmental impacts, including effects on non-target organisms, water quality, soil health, and biodiversity. To minimize these risks, the implementation of strategies such as buffer zones, careful application timing, and integrated pest management is crucial for promoting sustainable and environmentally friendly pest control practices.

3.3. Human Health Concerns:

Exposure to chemical pesticides poses potential health risks to individuals, particularly those involved in agricultural activities. Several studies have highlighted the adverse health effects associated with pesticide exposure, including acute poisoning, respiratory issues, neurological disorders, and reproductive health concerns Lekei et al. (2014), Jallow et al., 2017; , Damalas & Koutroubas, 2017). Furthermore, pesticide residues in food commodities have raised concerns about chronic health implications, such as cancer, endocrine disruption, and developmental disorders (Coppola et al., 2020; , Kilonzi et al., 2023). Occupational exposure to pesticides has been linked to acute and long-term health effects, emphasizing the need for effective safety measures and risk management strategies ("Assessment of Safety Practices of Pesticide Use among the Farmers in Adargunchi and Noolvi, Karnataka - A Cross Sectional Study", 2020; , El-Mageed et al., 2021). Additionally, inadequate safety practices and lack of protective measures among pesticide users have been identified as contributing factors to increased health risks (Arcury et al., 2018; , Kapeleka et al., 2021). Furthermore, the potential association between pesticide exposure and the risk of Parkinson's disease has been a subject of investigation, highlighting the need for comprehensive risk assessment and management (Ngowi et al., 2016; , George et al., 2017; , Li, 2017).

To address the potential health risks associated with chemical pesticide exposure, regulatory measures and safety precautions are essential. Proper training programs on pesticide safety, including the hazards of pesticide exposure, are crucial to enhance farmers' knowledge and safety practices (Jallow et al., 2017; , Damalas & Koutroubas, 2017). Regulatory authorities play a vital role in evaluating pesticide safety and setting appropriate risk mitigation measures to protect human health (He et al., 2022; , Knauer, 2016). The establishment of safety levels for pesticide residues in food commodities and the development of maximum residue limits (MRLs) are critical for ensuring food safety and protecting consumers from potential health hazards (El-Mageed et al., 2021; , Jara & Winter, 2019). Furthermore, the implementation of safety precautions, such as the use of protective clothing and adherence to safety guidelines, is essential to minimize health risks associated with pesticide use ("undefined", 2022). Human health risk assessment for pesticides involves hazard identification, dose-response assessment, exposure assessment, and risk characterization, providing a comprehensive framework for evaluating and managing health risks (Li, 2017).

In conclusion, the potential health risks associated with chemical pesticide exposure necessitate the implementation of regulatory measures and safety precautions to protect human health. Proper training, risk assessment, safety guidelines, and regulatory oversight are essential components of efforts to mitigate the health implications of pesticide exposure.

4. Emerging Trends and Alternative Approaches:

4. 1. Integrated Pest Management (IPM):

Integrated Pest Management (IPM) is a comprehensive approach to pest and disease management that aims to reduce reliance on chemical methods and minimize the environmental impact of pest control practices. IPM principles involve the judicious and coordinated use of multiple control techniques, integrating cultural, biological, and chemical strategies to manage pests and diseases below economically damaging levels Alyokhin et al. (2014), Bueno et al., 2017). By combining various pest control methods, IPM seeks to optimize pest management while minimizing the use of chemical pesticides, thereby promoting sustainable and environmentally friendly pest control practices.

Cultural control strategies, such as crop rotation, planting resistant varieties, and adjusting planting dates, are integral components of IPM. These practices aim to create unfavorable conditions for pests and diseases, reducing their impact on crops and minimizing the need for chemical interventions (Cooper et al., 2015; , Sawinska et al., 2020). Biological control methods, including the use of natural enemies, biopesticides, and pheromones, play a crucial role in IPM by targeting pests while minimizing adverse effects on non-target organisms and the environment (Furlan & Kreutzweiser, 2014; , Oliveira et al., 2021). Additionally, the selective use of chemical pesticides, based on monitoring and economic thresholds, is an important aspect of IPM, allowing for targeted and reduced pesticide applications when necessary (Khanal et al., 2021; , Khan et al., 2021).

The integration of these diverse control strategies in IPM provides a holistic and sustainable approach to pest and disease management. By reducing the reliance on chemical pesticides and promoting the use of alternative control methods, IPM contributes to the preservation of ecosystem health and biodiversity (Rejesus & Jones, 2020; , Ziska et al., 2018). Furthermore, the implementation of IPM practices has been shown to enhance economic benefits, reduce human and environmental health risks, and promote long-term sustainability in agricultural systems (Frische et al., 2018; , Hubert et al., 2019).

In conclusion, Integrated Pest Management (IPM) is a multifaceted approach that integrates cultural, biological, and chemical control strategies to effectively manage pests and diseases while minimizing reliance on chemical methods. By promoting sustainable and environmentally friendly pest control practices, IPM plays a crucial role in ensuring the long-term health and productivity of agricultural systems.

4.2. Biopesticides:

Biopesticides are a category of pest control agents derived from natural materials, such as animals, plants, bacteria, and certain minerals. They are considered an environmentally friendly alternative to conventional chemical pesticides, offering effective pest and disease management while minimizing adverse environmental and health impacts. Biopesticides can be broadly categorized into microbial-based and botanical-based formulations, each offering unique benefits and applications.

Microbial-based biopesticides are derived from microorganisms such as bacteria, fungi, and viruses. These formulations harness the natural antagonistic properties of microorganisms to control pests and diseases. For example, Bacillus thuringiensis (Bt) is a widely recognized microbial biopesticide that produces insecticidal proteins targeting specific insect pests. Similarly, Paenibacillus polymyxa and Beauveria bassiana are microbial biopesticides known for their biocontrol activities against various pests and pathogens Raymond & Federici (2017), Srinivasan et al., 2019; , Malinga & Laing, 2022).

Botanical-based biopesticides, on the other hand, are derived from plant extracts or essential oils with pesticidal properties. Compounds such as azadirachtin from neem, pyrethrins from chrysanthemum, and rotenone from derris are examples of botanical biopesticides widely used for pest control. These formulations offer a natural and sustainable approach to pest management, with minimal impact on non-target organisms and the environment (Ndakidemi et al., 2021; , Lima et al., 2015).

The effectiveness of biopesticides lies in their ability to target specific pests and diseases while posing minimal risk to beneficial organisms, humans, and the environment. They offer a sustainable pest management solution by reducing the reliance on synthetic chemical pesticides and promoting ecological balance in agroecosystems. Additionally, biopesticides have shown promise in integrated pest management (IPM) programs, where they are integrated with other pest control methods to achieve comprehensive and sustainable pest management (Kowalska et al., 2020; , Bejarano & Puopolo, 2020; , Seiber et al., 2014).

Safety is a key consideration in the use of biopesticides, as they are designed to minimize adverse effects on human health and the environment. Their natural origins and selective modes of action contribute to their safety profile, making them suitable for use in organic farming and environmentally sensitive areas. Furthermore, biopesticides are known for their compatibility with beneficial organisms, making them an integral component of ecologically sustainable pest management strategies (Constantine et al., 2020; , Yan et al., 2021).

In conclusion, biopesticides offer a promising and sustainable approach to pest and disease management in agriculture. Their effectiveness, safety, and potential for integrated pest management make them valuable tools for promoting environmentally friendly and sustainable agricultural practices.

5. Conclusion:

Over the years, significant advancements have been made in chemical methods for pest and disease control in agriculture. Research has led to the development of novel chemical pesticides with improved efficacy and reduced environmental impact. The discovery and commercialization of new active ingredients, such as neonicotinoids, pyrethroids, and herbicides with different modes of action, have expanded the options for pest and disease management. Additionally, advancements in formulation technologies have enhanced the delivery and performance of chemical pesticides, improving their effectiveness in controlling a wide range of pests and diseases in various crops. Despite the advancements in chemical methods for pest and disease control, several challenges and concerns persist in pesticide use. One of the primary concerns is the development of pesticide resistance in target pest populations, leading to reduced efficacy of chemical pesticides. Environmental contamination and non-target organism toxicity are also significant concerns associated with pesticide use. Emerging trends in pesticide use include the increasing focus on precision application technologies, the development of bio-based pesticides, and the integration of digital tools for pest monitoring and management. However, the overreliance on chemical pesticides and the potential impact on human health and the environment remain critical challenges in pesticide use. In light of the challenges and concerns associated with pesticide use, there is a growing recognition of the importance of adopting sustainable and integrated approaches to minimize reliance on chemical methods and promote environmentally friendly pest and disease management strategies. Integrated Pest Management (IPM) has emerged as a holistic approach that combines cultural, biological, and chemical control methods to achieve effective pest and disease management while minimizing the use of chemical pesticides. Sustainable pest management practices, including the use of biopesticides, crop rotation, and habitat manipulation, are gaining prominence as alternatives to conventional chemical methods. By integrating diverse pest control strategies and promoting ecological balance, sustainable and integrated approaches aim to reduce the environmental impact of pest and disease management while ensuring long-term agricultural sustainability.

6. References

1. (2020). Assessment of safety practices of pesticide use among the farmers in adargunchi and noolvi, karnataka - a cross sectional study. Indian Journal of Public Health Research & Development. https://doi.org/10.37506/ijphrd.v11i7.10082
2. (2020). Crop disease and insect pest automatic monitoring and reporting system based on internet of things technology. International Journal of Multimedia Computing, 1(1). https://doi.org/10.38007/ijmc.2020.010101
3. (2020). Farmers' perceptions of integrated pest management (ipm) and determinants of adoption in vegetable production in bangladesh. International Journal of Pest Management, 68(2), 158-166. https://doi.org/10.1080/09670874.2020.1807653
4. (2022). Untitled. Agricultural Extension Journal, 06(04). https://doi.org/10.22377/aextj.v6i4.341
5. Abu, N., Bukhari, W., Ong, C., Kassim, A., Izzuddin, T., Sukhaimie, M., … & Rasid, A. (2022). Internet of things applications in precision agriculture: a review. Journal of Robotics and Control (Jrc), 3(3), 338-347. https://doi.org/10.18196/jrc.v3i3.14159
6. Alengebawy, A., Abdelkhalek, S., Qureshi, S., & Wang, M. (2021). Heavy metals and pesticides toxicity in agricultural soil and plants: ecological risks and human health implications. Toxics, 9(3), 42. https://doi.org/10.3390/toxics9030042
7. Alhadidi, S. (2023). A review of entomopathogenic fungi of iraq. Iraqi Journal of Science, 91-110. https://doi.org/10.24996/ijs.2023.64.1.10
8. Alyokhin, A., Mota‐Sánchez, D., Baker, M., Snyder, W., Menasha, S., Whalon, M., … & Moarsi, W. (2014). The red queen in a potato field: integrated pest management versus chemical dependency in colorado potato beetle control. Pest Management Science, 71(3), 343-356. https://doi.org/10.1002/ps.3826
9. Arcury, T., Laurienti, P., Talton, J., Chen, H., Howard, T., Barr, D., … & Quandt, S. (2018). Pesticide urinary metabolites among latina farmworkers and nonfarmworkers in north carolina. Journal of Occupational and Environmental Medicine, 60(1), e63-e71. https://doi.org/10.1097/jom.0000000000001189
10. Barzman, M., Bàrberi, P., Birch, A., Boonekamp, P., Dachbrodt-Saaydeh, S., Graf, B., … & Sattin, M. (2015). Eight principles of integrated pest management. Agronomy for Sustainable Development, 35(4), 1199-1215. https://doi.org/10.1007/s13593-015-0327-9
11. Barzman, M., Bàrberi, P., Birch, A., Boonekamp, P., Dachbrodt-Saaydeh, S., Graf, B., … & Sattin, M. (2015). Eight principles of integrated pest management. Agronomy for Sustainable Development, 35(4), 1199-1215. https://doi.org/10.1007/s13593-015-0327-9
12. Bejarano, A. and Puopolo, G. (2020). Bioformulation of microbial biocontrol agents for a sustainable agriculture., 275-293. https://doi.org/10.1007/978-3-030-53238-3_16
13. Bosch, F., Lopez‐Ruiz, F., Oliver, R., Paveley, N., Helps, J., & Berg, F. (2017). Identifying when it is financially beneficial to increase or decrease fungicide dose as resistance develops. Plant Pathology, 67(3), 549-560. https://doi.org/10.1111/ppa.12787
14. Brunharo, C. and Streisfeld, M. (2022). Multiple evolutionary origins of glyphosate resistance in lolium multiflorum. Evolutionary Applications, 15(2), 316-329. https://doi.org/10.1111/eva.13344
15. Bueno, A., Carvalho, G., Santos, A., Sosa–Gómez, D., & Silva, D. (2017). Pesticide selectivity to natural enemies: challenges and constraints for research and field recommendation. Ciência Rural, 47(6).

https://doi.org/10.1590/0103-8478cr20160829
16. Carluer, N., Lauvernet, C., Noll, D., & Muñoz-Carpena, R. (2017). Defining context-specific scenarios to design vegetated buffer zones that limit pesticide transfer via surface runoff. The Science of the Total Environment, 575, 701-712. https://doi.org/10.1016/j.scitotenv.2016.09.105
17. Chandler, J., Preisendanz, H., Veith, T., Elkin, K., Elliott, H., Watson, J., … & Kleinman, P. (2021). Role of concentrated flow pathways on the movement of pesticides through agricultural fields and riparian buffer zones. Transactions of the Asabe, 64(3), 975-986. https://doi.org/10.13031/trans.14221
18. Chavan, V. and Borkar, S. (2020). Strategies for management of fungicide resistance in tomato leaf blight pathogen alternaria solani in 10 districts of western maharashtra in india. GSC Biological and Pharmaceutical Sciences, 12(3), 180-188. https://doi.org/10.30574/gscbps.2020.12.3.0280
19. Constantine, K., Kansiime, M., Mugambi, I., Nunda, W., Chacha, D., Rware, H., … & Day, R. (2020). Why don't smallholder farmers in kenya use more biopesticides?. Pest Management Science, 76(11), 3615-3625. https://doi.org/10.1002/ps.5896
20. Cooper, R., Wang, C., & Singh, N. (2015). Evaluation of a model community-wide bed bug management program in affordable housing. Pest Management Science, 72(1), 45-56. https://doi.org/10.1002/ps.3982
21. Coppola, L., Tait, S., Ciferri, L., Frustagli, G., Merola, C., Perugini, M., … & Rocca, C. (2020). Integrated approach to evaluate the association between exposure to pesticides and idiopathic premature thelarche in girls: the peach project. International Journal of Molecular Sciences, 21(9), 3282. https://doi.org/10.3390/ijms21093282
22. Cunha, J., Chueca, P., Garcerá, C., & Moltó, E. (2012). Risk assessment of pesticide spray drift from citrus applications with air-blast sprayers in spain. Crop Protection, 42, 116-123. https://doi.org/10.1016/j.cropro.2012.06.001
23. Damalas, C. and Koutroubas, S. (2017). Farmers' training on pesticide use is associated with elevated safety behavior. Toxics, 5(3), 19. https://doi.org/10.3390/toxics5030019
24. Dey, U., Sarkar, S., Malik, M., Sehgal, M., Debbarma, P., & Chander, S. (2021). A promising sustainable pest management technology: microbial bio-control agent. Microbiology Research Journal International, 23-26. https://doi.org/10.9734/mrji/2021/v31i1230361
25. Dong, H., Huang, Y., & Wang, K. (2021). The development of herbicide resistance crop plants using crispr/cas9-mediated gene editing. Genes, 12(6), 912. https://doi.org/10.3390/genes12060912
26. Edi, C., Koudou, B., Jones, C., Weetman, D., & Ranson, H. (2012). Multiple-insecticide resistance inanopheles gambiaemosquitoes, southern côte d'ivoire. Emerging Infectious Diseases, 18(9), 1508-1511. https://doi.org/10.3201/eid1809.120262
27. El-Mageed, N., Abu-Abdoun, I., Kayaf, K., & Janaan, A. (2021). Monitoring of pesticide residues in imported datepalm fruits in united arab emirates. European Journal of Nutrition & Food Safety, 1-9. https://doi.org/10.9734/ejnfs/2021/v13i830438
28. Elderfield, J., Lopez-Ruiz, F., Bosch, F., & Cunniffe, N. (2017). Using epidemiological principles to explain fungicide resistance management strategies: why do mixtures outperform alternations?.. https://doi.org/10.1101/168831
29. Fahad, S., Hussain, S., Khan, F., Khan, F., Saud, S., Muhammad, H., … & Huang, J. (2015). Rice pest management and biological control., 85-106. https://doi.org/10.1007/978-3-319-16988-0_4
30. Frische, T., Egerer, S., Matezki, S., Pickl, C., & Wogram, J. (2018). 5-point programme for sustainable plant protection. Environmental Sciences Europe, 30(1). https://doi.org/10.1186/s12302-018-0136-2
31. Furlan, L. and Kreutzweiser, D. (2014). Alternatives to neonicotinoid insecticides for pest control: case studies in agriculture and forestry. Environmental Science and Pollution Research, 22(1), 135-147. https://doi.org/10.1007/s11356-014-3628-7
32. Ganie, Z., Obrigawitch, T., Kang, I., Copeland, D., Gutteridge, S., May, J., … & Chandi, A. (2020). An outlook of fmc's current and future herbicide-resistance management strategies. Pest Management Science, 77(4), 1559-1563. https://doi.org/10.1002/ps.5865

33. George, S., Yassa, H., Abdelwarith, A., & Mahmoud, M. (2017). Exposure to pesticides as a risk factor for parkinson's disease. Zagazig Journal of Forensic Medicine, 15(2), 12-25. https://doi.org/10.21608/zjfm.2017.4777
34. Guedes, R., Smagghe, G., Stark, J., & Desneux, N. (2016). Pesticide-induced stress in arthropod pests for optimized integrated pest management programs. Annual Review of Entomology, 61(1), 43-62. https://doi.org/10.1146/annurev-ento-010715-023646
35. Hagstrum, D. and Phillips, T. (2017). Evolution of stored-product entomology: protecting the world food supply. Annual Review of Entomology, 62(1), 379-397. https://doi.org/10.1146/annurev-ento-031616-035146
36. Hawkins, N., Bass, C., Dixon, A., & Neve, P. (2018). The evolutionary origins of pesticide resistance. Biological Reviews, 94(1), 135-155. https://doi.org/10.1111/brv.12440
37. He, L., Huang, Y., & Tang, X. (2022). Rnai-based pest control: production, application and the fate of dsrna. Frontiers in Bioengineering and Biotechnology, 10. https://doi.org/10.3389/fbioe.2022.1080576
38. Hollomon, D. (2015). Fungicide resistance: facing the challenge - a review. Plant Protection Science, 51(4), 170-176. https://doi.org/10.17221/42/2015-pps
39. Hough, J., Howard, J., Brown, S., Portwood, D., Kilby, P., & Dickman, M. (2022). Strategies for the production of dsrna biocontrols as alternatives to chemical pesticides. Frontiers in Bioengineering and Biotechnology, 10. https://doi.org/10.3389/fbioe.2022.980592
40. Hubert, T., Miller, J., & Burkett, D. (2019). A brief introduction to integrated pest management for aquatic systems. North American Journal of Fisheries Management, 41(2), 264-275. https://doi.org/10.1002/nafm.10331
41. Islam, M., Shamsuzzoha, M., Rahman, M., Bari, M., Akter, M., Khatun, A., … & Uddin, M. (2019). Effect of bagging time on fruit quality and shelf life of mango (mangifera indica l.) cv. langra in bangladesh. International Journal of Agriculture Environment and Bioresearch, 4(4), 279-289. https://doi.org/10.35410/ijaeb.2019.4424
42. Jallow, M., Awadh, D., Albaho, M., Devi, V., & Thomas, B. (2017). Pesticide knowledge and safety practices among farm workers in kuwait: results of a survey. International Journal of Environmental Research and Public Health, 14(4), 340. https://doi.org/10.3390/ijerph14040340
43. Jangid, A., Shringi, A., Chakma, M., Srivastava, S., & Rana, M. (2022). Evaluation of biocontrol agents and fungicides against alternaria leaf spot of spinach. Agricultural Science Digest - A Research Journal, (Of). https://doi.org/10.18805/ag.d-5657
44. Jara, E. and Winter, C. (2019). Safety levels for organophosphate pesticide residues on fruits, vegetables, and nuts. International Journal of Food Contamination, 6(1). https://doi.org/10.1186/s40550-019-0076-7
45. Jugulam, M. and Gill, B. (2017). Molecular cytogenetics to characterize mechanisms of gene duplication in pesticide resistance. Pest Management Science, 74(1), 22-29. https://doi.org/10.1002/ps.4665
46. Kapeleka, J., Sauli, E., Sadik, O., & Ndakidemi, P. (2021). Changing patterns and drivers of increased pesticides use in smallholder vegetable production systems in tanzania.. https://doi.org/10.1101/2021.01.18.427098
47. Katsuta, H., Nomura, M., Wakita, T., Daido, H., Kobayashi, Y., Kawahara, A., … & Banba, S. (2019). Discovery of broflanilide, a novel insecticide. Journal of Pesticide Science, 44(2), 120-128. https://doi.org/10.1584/jpestics.d18-088
48. Khan, F., Manzoor, S., Gul, H., Ali, M., Bashir, M., Akmal, M., … & Joseph, S. (2021). Drivers of farmers' intention to adopt integrated pest management: a case study of vegetable farmers in pakistan. Ecosphere, 12(10). https://doi.org/10.1002/ecs2.3812
49. Khanal, A., Regmi, P., Bahadur, K., Bahadur, K., & Dahal, K. (2021). Performance of ipm techniques on pesticide use and yield of vegetables. Agricultural Science Digest - A Research Journal, (Of). https://doi.org/10.18805/ag.d-5273
50. Kienzler, A., Barron, M., Belanger, S., Beasley, A., & Embry, M. (2017). Mode of action (moa) assignment classifications for ecotoxicology: an evaluation of approaches. Environmental Science & Technology, 51(17), 10203-10211. https://doi.org/10.1021/acs.est.7b02337
51. Kilonzi, J., Nyongesa, M., & Ng'ang'a, N. (2023). Pesticides handling, risk management and estimation of exposure levels in potato farming under small scale production.. https://doi.org/10.21203/rs.3.rs-2889820/v1

52. Knauer, K. (2016). Pesticides in surface waters: a comparison with regulatory acceptable concentrations (racs) determined in the authorization process and consideration for regulation. Environmental Sciences Europe, 28(1). https://doi.org/10.1186/s12302-016-0083-8
53. Kole, R., Roy, K., Panja, B., Sankarganesh, E., Manda, T., & Worede, R. (2019). Use of pesticides in agriculture and emergence of resistant pests. Indian Journal of Animal Health, 58(2-SPL), 53. https://doi.org/10.36062/ijah.58.2spl.2019.53-70
54. Kowalska, J., Tyburski, J., Matysiak, K., Tylkowski, B., & Malusa, E. (2020). Field exploitation of multiple functions of beneficial microorganisms for plant nutrition and protection: real possibility or just a hope?. Frontiers in Microbiology, 11. https://doi.org/10.3389/fmicb.2020.01904
55. Küpper, A., Peter, F., Zöllner, P., Lorentz, L., Tranel, P., Beffa, R., … & Gaines, T. (2018). Tembotrione detoxification in 4-hydroxyphenylpyruvate dioxygenase (hppd) inhibitor-resistant palmer amaranth (amaranthus palmeri s. wats.). Pest Management Science, 74(10), 2325-2334. https://doi.org/10.1002/ps.4786
56. Lagator, M., Vogwill, T., Mead, A., Colegrave, N., & Neve, P. (2013). Herbicide mixtures at high doses slow the evolution of resistance in experimentally evolving populations of chlamydomonas reinhardtii. New Phytologist, 198(3), 938-945. https://doi.org/10.1111/nph.12195
57. Landwehr, A. (2021). Benefits of baculovirus use in ipm strategies for open field and protected vegetables. Frontiers in Sustainable Food Systems, 4. https://doi.org/10.3389/fsufs.2020.593796
58. Larue, C., Goley, M., Shi, L., Evdokimov, A., Sparks, O., Ellis, C., … & Varagona, M. (2019). Development of enzymes for robust aryloxyphenoxypropionate and synthetic auxin herbicide tolerance traits in maize and soybean crops. Pest Management Science, 75(8), 2086-2094. https://doi.org/10.1002/ps.5393
59. Lekei, E., Ngowi, A., & London, L. (2014). Farmers' knowledge, practices and injuries associated with pesticide exposure in rural farming villages in tanzania. BMC Public Health, 14(1). https://doi.org/10.1186/1471-2458-14-389
60. Li, Z. (2017). Human health risk assessment and management of pesticides. Toxicology Open Access, 03(03). https://doi.org/10.4172/2476-2067.1000e125
61. Lima, D., Melo, J., Guedes, N., Gontijo, L., Guedes, R., & Gondim, M. (2015). Bioinsecticide-predator interactions: azadirachtin behavioral and reproductive impairment of the coconut mite predator neoseiulus baraki. Plos One, 10(2), e0118343. https://doi.org/10.1371/journal.pone.0118343
62. Liu, X., Merchant, A., Xiang, S., Zong, T., Zhou, X., & Bai, L. (2020). Managing herbicide resistance in china. Weed Science, 69(1), 4-17. https://doi.org/10.1017/wsc.2020.68
63. Malinga, L. and Laing, M. (2022). Role of microbial biopesticides as an alternative to insecticides in integrated pest management of cotton pests.. https://doi.org/10.5772/intechopen.100400
64. Mantzoukas, S. and Eliopoulos, P. (2020). Endophytic entomopathogenic fungi: a valuable biological control tool against plant pests. Applied Sciences, 10(1), 360. https://doi.org/10.3390/app10010360
65. Masiello, M., Somma, S., Ghionna, V., Logrieco, A., & Moretti, A. (2019). In vitro and in field response of different fungicides against aspergillus flavus and fusarium species causing ear rot disease of maize. Toxins, 11(1), 11. https://doi.org/10.3390/toxins11010011
66. Mostafanezhad, H., Edin, E., Grenville-Briggs, L., Lankinen, Å., & Liljeroth, E. (2021). Rapid emergence of boscalid resistance in swedish populations of alternaria solani revealed by a combination of field and laboratory experiments. European Journal of Plant Pathology, 162(2), 289-303. https://doi.org/10.1007/s10658-021-02403-8
67. Nagai, T. (2017). Predicting herbicide mixture effects on multiple algal species using mixture toxicity models. Environmental Toxicology and Chemistry, 36(10), 2624-2630. https://doi.org/10.1002/etc.3800
68. Ndakidemi, B., Mbega, E., Ndakidemi, P., Stevenson, P., Belmain, S., Arnold, S., … & Woolley, V. (2021). Natural pest regulation and its compatibility with other crop protection practices in smallholder bean farming systems. Biology, 10(8), 805. https://doi.org/10.3390/biology10080805
69. Ngowi, A., Mrema, E., & Kishinhi, S. (2016). Pesticide health and safety challenges facing informal sector workers. New Solutions a

Journal of Environmental and Occupational Health Policy, 26(2), 220-240. https://doi.org/10.1177/1048291116650262

70. Odilbekov, F., Edin, E., Mostafanezhad, H., Coolman, H., Grenville-Briggs, L., & Liljeroth, E. (2019). Within-season changes in alternaria solani populations in potato in response to fungicide application strategies. European Journal of Plant Pathology, 155(3), 953-965. https://doi.org/10.1007/s10658-019-01826-8
71. Oliveira, J., Santana, W., Altoé, J., Carrion, P., Baldan, W., Lima, A., … & Oliveira, V. (2021). Integrated pest management in coffee. International Journal of Plant & Soil Science, 9-16. https://doi.org/10.9734/ijpss/2021/v33i1430496
72. Oršolić, D., Pehar, V., Šmuc, T., & Stepanić, V. (2021). Comprehensive machine learning based study of the chemical space of herbicides. Scientific Reports, 11(1). https://doi.org/10.1038/s41598-021-90690-w
73. Passeport, E., Tournebize, J., Chaumont, C., Guenne, A., & Coquet, Y. (2013). Pesticide contamination interception strategy and removal efficiency in forest buffer and artificial wetland in a tile-drained agricultural watershed. Chemosphere, 91(9), 1289-1296. https://doi.org/10.1016/j.chemosphere.2013.02.053
74. Poudel, D., Bashyal, S., & Gautam, B. (2022). A review on cultural practice as an effective pest management approach under integrated pest management. Tropical Agroecosystems, 3(1), 34-40. https://doi.org/10.26480/taec.01.2022.34.40
75. Ramdial, H., Abreu, K., & Rampersad, S. (2017). Fungicide sensitivity among isolates of colletotrichum truncatum and fusarium incarnatum-equiseti species complex infecting bell pepper in trinidad. The Plant Pathology Journal, 33(2), 118-124. https://doi.org/10.5423/ppj.oa.06.2016.0138
76. Raymond, B. and Federici, B. (2017). In defence of bacillus thuringiensis, the safest and most successful microbial insecticide available to humanity—a response to efsa. Fems Microbiology Ecology, 93(7). https://doi.org/10.1093/femsec/fix084
77. Rejesus, R. and Jones, M. (2020). Perspective: enhancing economic evaluations and impacts of integrated pest management farmer field schools (ipm-ffs) in low-income countries. Pest Management Science, 76(11), 3527-3536. https://doi.org/10.1002/ps.5912
78. Rugalema, G. and Mnyone, L. (2020). Indiscriminate use of agro-veterinary pesticides in plague endemic foci in tanzania: potential risk for development of insecticide resistance in flea vectors.. https://doi.org/10.21203/rs.3.rs-36506/v1
79. Rwomushana, I., Bateman, M., Beale, T., Beseh, P., Cameron, K., Chiluba, M., … & Tambo, J. (2017). Fall armyworm: impacts and implications for africa. Outlooks on Pest Management, 28(5), 196-201. https://doi.org/10.1564/v28_oct_02
80. S, A. and Thangapandiyan, S. (2019). Comparative bioassay of silver nanoparticles and malathion on infestation of red flour beetle, tribolium castaneum. The Journal of Basic and Applied Zoology, 80(1). https://doi.org/10.1186/s41936-019-0124-0
81. Savary, S., Willocquet, L., Pethybridge, S., Esker, P., McRoberts, N., & Nelson, A. (2019). The global burden of pathogens and pests on major food crops. Nature Ecology & Evolution, 3(3), 430-439. https://doi.org/10.1038/s41559-018-0793-y
82. Sawinska, Z., Świtek, S., Głowicka-Wołoszyn, R., & Kowalczewski, P. (2020). Agricultural practice in poland before and after mandatory ipm implementation by the european union. Sustainability, 12(3), 1107. https://doi.org/10.3390/su12031107
83. Seiber, J., Coats, J., Duke, S., & Gross, A. (2014). Biopesticides: state of the art and future opportunities. Journal of Agricultural and Food Chemistry, 62(48), 11613-11619. https://doi.org/10.1021/jf504252n
84. Sen, M., Hamouzová, K., Košnarová, P., Roy, A., & Soukup, J. (2022). Herbicide resistance in grass weeds: epigenetic regulation matters too. Frontiers in Plant Science, 13. https://doi.org/10.3389/fpls.2022.1040958
85. Seyi-Amole, D. and Onilude, A. (2021). Microbiological control: a new age of maize production.. https://doi.org/10.5772/intechopen.97464
86. Shah, R. and Shad, S. (2019). House fly resistance to chlorantraniliprole: cross resistance patterns, stability and associated fitness costs. Pest Management Science, 76(5), 1866-1873. https://doi.org/10.1002/ps.5716
87. Shawer, R., Donati, I., Cellini, A., Spinelli, F., & Mori, N. (2018). Insecticidal activity of photorhabdus luminescens against drosophila suzukii. Insects, 9(4), 148. https://doi.org/10.3390/insects9040148

88. Shimada, B., Simon, M., Silva, V., Schmidt, J., Sackser, G., & Kiahara, L. (2021). Problems of chemical control in agriculture: a social perspective. Journal of Scientific Research and Reports, 49-55. https://doi.org/10.9734/jsrr/2021/v27i930435
89. Siviter, H. and Muth, F. (2020). Do novel insecticides pose a threat to beneficial insects?. Proceedings of the Royal Society B Biological Sciences, 287(1935), 20201265. https://doi.org/10.1098/rspb.2020.1265
90. Sonhafouo-Chiana, N., Nkahe, L., Kopya, E., Awono-Ambene, P., Wanji, S., Wondji, C., … & Antonio-Nkondjio, C. (2022). Rapid evolution of insecticide resistance and patterns of pesticides usage in agriculture in the city of yaoundé, cameroon. Parasites & Vectors, 15(1). https://doi.org/10.1186/s13071-022-05321-8
91. Sparks, T., Storer, N., Porter, A., Slater, R., & Nauen, R. (2021). Insecticide resistance management and industry: the origins and evolution of the insecticide resistance action committee (irac) and the mode of action classification scheme. Pest Management Science, 77(6), 2609-2619. https://doi.org/10.1002/ps.6254
92. Srinivasan, R., Subramanian, S., Ekesi, S., & Tamò, M. (2019). Biopesticide based sustainable pest management for safer production of vegetable legumes and brassicas in asia and africa. Pest Management Science, 75(9), 2446-2454. https://doi.org/10.1002/ps.5480
93. Tang, Y., Chen, C., & Leite, A. (2023). Editorial: precision control technology and application in agricultural pest and disease control. Frontiers in Plant Science, 14. https://doi.org/10.3389/fpls.2023.1163839
94. Thia, J., Maino, J., Kelly, A., Hoffmann, A., & Umina, P. (2022). Expanding risk predictions of pesticide resistance evolution in arthropod pests with a proxy for selection pressure.. https://doi.org/10.1101/2022.04.18.488707
95. Vila-Aiub, M. (2019). Fitness of herbicide-resistant weeds: current knowledge and implications for management. Plants, 8(11), 469. https://doi.org/10.3390/plants8110469
96. Wato, T. (2020). The role of allelopathy in pest management and crop production – a review. FSQM. https://doi.org/10.7176/fsqm/93-02
97. Willyerd, K., Li, C., Madden, L., Bradley, C., Bergstrom, G., Sweets, L., … & Paul, P. (2012). Efficacy and stability of integrating fungicide and cultivar resistance to manage fusarium head blight and deoxynivalenol in wheat. Plant Disease, 96(7), 957-967. https://doi.org/10.1094/pdis-09-11-0763
98. Yan, S., Hu, Q., Jiang, Q., Chen, H., Wei, J., Yin, M., … & Shen, J. (2021). Simple osthole/nanocarrier pesticide efficiently controls both pests and diseases fulfilling the need of green production of strawberry. Acs Applied Materials & Interfaces, 13(30), 36350-36360. https://doi.org/10.1021/acsami.1c09887
99. Yang, L., He, M., Ouyang, H., Zhu, W., Pan, Z., QiJun, S., … & Zhan, J. (2019). Cross-resistance of the pathogenic fungus alternaria alternata to fungicides with different modes of action. BMC Microbiology, 19(1). https://doi.org/10.1186/s12866-019-1574-8
100. Yeşilayer, A. (2018). Efficiency of two different entomopathogen fungi beauveria bassiana and purpureocillium lilacinum tr1 against tetranychus urticae. Applied Ecology and Environmental Research, 16(5), 6077-6086. https://doi.org/10.15666/aeer/1605_60776086
101. Ziska, L., Bradley, B., Wallace, R., Bargeron, C., LaForest, J., Choudhury, R., … & Vega, F. (2018). Climate change, carbon dioxide, and pest biology, managing the future: coffee as a case study. Agronomy, 8(8), 152. https://doi.org/10.3390/agronomy8080152
102. Zytynska, S., Eicher, M., Fahle, R., & Weisser, W. (2021). Effect of flower identity and diversity on reducing aphid populations via natural enemy communities. Ecology and Evolution, 11(24), 18434-18445. https://doi.org/10.1002/ece3.8432