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Impact Of Pesticides On Agriculture, Environment And Human Health: A Comprehensive Review)

Ruchi Kohli[1], Anu Mittal[2]✉

[1]Assistant Professor, Department of Chemistry, Guru Nanak Dev University College, Narot Jaimal Singh-145026, (Punjab) India
[2] Assistant Professor, Department of Chemistry, Guru Nanak Dev University College, Patti-143416, (Punjab) India

Abstract: Exploring the historical evolution of pesticides, the article navigates through the different classifications of pesticides and explores various impacts of pesticides on agriculture, the environment, and human health. It examines global trends in pesticide application, sheds light on variations across regions and crops. The ecological consequences such as effects on non-target species, soil health, and water quality of pesticide use are discussed. The presence of pesticide residues in food products and potential implications for human health, prompt a discussion on regulatory measures. A critical analysis of the relationship between pesticide exposure and health issues, emphasizes the delicate balance needed in pesticide use. The article evaluates existing global regulations governing pesticide use and identifies challenges in implementation and enforcement. Shifting towards sustainable pest management practices, alternative methods such as biological control, organic farming, and precision agriculture are explored. The review also highlights the future directions and research needs in this field. It concludes with a call for a multidisciplinary and collaborative approach to address the challenges posed by pesticide use, emphasizing the need to balance agricultural productivity with environmental and health concerns.

Index Terms - Pesticides, health, environment, agriculture

I. Introduction

1.1 Historical development of pesticides

The green revolution, while boosting agricultural productivity, simultaneously introduced a dependence on intensive pesticide use. In pursuit of higher yields, farmers increasingly turned to chemical pesticides, leading to environmental concerns. The unwanted consequence of this agricultural transformation poses challenges for sustainability and ecosystem health. The historical development and evolution of pesticides span thousands of years, evolving from early undeveloped, nature-based practices to the sophisticated chemical formulations and integrated pest management strategies employed today. In ancient civilizations, early farmers relied on plant extracts and inorganic compounds like sulfur and arsenic to control pests. The Middle Ages witnessed the continued use of natural substances such as nicotine and rotenone. By the 17th to 19th centuries, the introduction of chemical compounds like mercury and lead arsenate marked a significant shift. The early 20th century marked the introduction of synthetic pesticides, exemplified by the discovery of DDT in the 1940s. The post-World War II era saw a boom in chemical pesticide development, addressing agricultural and public health needs. However, growing environmental concerns, notably catalyzed by Rachel Carson's "Silent Spring," raised awareness about environmental effects of DDT, prompted regulatory responses and a shift towards Integrated Pest Management (IPM) strategies. The late 20th century and beyond brought innovations in biological pesticides, genetically modified crops, and sustainable practices, emphasizing a holistic approach to pest control.

1.2 Pesticides in modern agriculture

Modern agriculture faces challenge of producing sufficient food to feed a growing global population while also addressing concerns related to environment sustainability. Pesticides are very important in modern agriculture for crop protection and yield enhancement. Pesticides play a critical role in safeguarding crops from a variety of destructive pests, diseases, and weeds that pose threats to agricultural productivity. By effectively controlling these biological negatives, pesticides help prevent crop losses and ensure a stable food supply. Moreover, they contribute to enhanced crop yields by reducing the impact of pests that can diminish the quality and quantity of harvests. In a rapidly growing global population, where food security is a serious concern, the judicious use of pesticides becomes integral to meet the increasing demand for agricultural products. While recognizing the significance of pesticides in securing harvests, it is essential to balance their use with environmentally sustainable practices and regulatory frameworks to minimize potential adverse effects on ecosystems and human health.

1.3 Benefits and drawbacks of pesticides use

Indiscriminate use of pesticides, intended to enhance productivity, leads to environmental pollution and harm to non target species. The need for a balanced understanding of the benefits and potential drawbacks of pesticides is crucial in understanding the complexities of modern agriculture. Pesticides offer significant benefits, playing a pivotal role in protecting crops from pests, diseases, and weeds, thereby ensuring stable and increased yields. Pesticides can be a cost effective solution compared to potential losses without protection. Pesticides contribute to better crop quality, ensuring that produce meets market standards. However, a subtle perspective is essential due to the potential drawbacks associated with pesticide use. Environmental concerns, including the impact on non-target species, soil health, water contamination, and the development of pesticide-resistant pests, emphasize the need for a measured and thoughtful approach. Additionally, human health considerations and the potential residues of pesticides in food products necessitate careful management. Overreliance on certain pesticides can render the chemicals less effective over time, leading to development of resistance in target pests. Striking a balance requires integrating sustainable agricultural practices, implementing alternative pest control methods, and adhering to strict regulations to minimize harmful effects on ecosystems and human well-being.

2 Classification of Pesticides

The term "pesticides" encompasses around 1000 different chemical substances and their usage in agriculture and livestock has steadily risen since 1950s. Pesticides are evaluated based on various criteria, including toxicity, target organisms, chemical composition, mode of entry, mode of action, and sources of origin.

2.1 Classification of pesticides according to its toxicity:

WHO class	Degree of hazard	LD50 for rats (mg/kg of body weight)	
		Oral	Dermal
Class Ia	Enormously Hazardous	< 5	< 5
Class Ib	Highly Hazardous	5 to 50	5 to 200
Class II	Reasonably Hazardous	50 to 2000	200 to 2000
Class III	Somewhat Hazardous	> 2000	> 2000
Class V	Unlikely to present acute hazard	5000 or higher	

2.2 Classification of pesticides according to chemical composition

The primary and widely accepted method for classifying pesticides is based on their chemical composition. This approach categorizes pesticides, including insecticides, fungicides, herbicides and rodenticides according to specific chemical compositions:

Insecticides: chemically classified into organophosphates (Monocrotophos), pyrethroids (permethrin), organochlorines (Endosulfan), carbamates (carbaryl), neonicotinoids (imidacloprid), phenylpyrazoles, various pesticides like Antibiotics (Abamectin), Spinosyns (Spinosad), Benzolureas (diflubenzuron) etc.

Fungicides: categorized as dicarboximides (famoxadone), inorganic dithiocarbamates, amide fungicides (carpropamid), strobilurin, aliphatic nitrogen fungicides (dodine), anilides, (benz)imidazoles, aromatic fungicides (chlorothalonil), dinitrophenol fungicides (dinocap) and conazoles etc.

Herbicides: Encompasses amides, dinitroanilines, anilide herbicide (flufenacet), urea herbicides, chlorophenoxy, bipyridyls, triazines, aminophosphonates quaternary ammonium herbicides (Paraquat), sulfonylurea herbicides (chlorimuron), chlorotriazine herbicides (atrazine) etc.

Rodenticides: classified as organic coumarin rodenticides (bromadiolone, coumatetralyl), inorganic rodenticides (Aluminium phosphide and Zinc Phosphide) etc.

2.3 Classification based on the pest they kill and their functions:

Insecticides are designed to combat insect pests, preventing damage to crops and ensuring optimal yields. Herbicides, on the other hand, are formulated to control weeds, which compete with crops for nutrients and sunlight. Fungicides play a crucial role in preventing and managing fungal diseases that can compromise the health of plants. Rodenticides are specialized to control rodent populations, addressing potential threats to both crops and stored produce. Bactericides are agents that either kill or inhibit bacterial growth. Acaricides are designed to eliminate mites and ticks. Antifeedants are substances that deter insects and pests from feeding. Larvicides are compounds designed to prevent the growth of larvae. Virucides are agents with antiviral properties. Nematicides are chemicals employed to eliminate nematodes. Dessicants refer to agents that function by drying out plant tissues. Ovicides impede the development of insect and mite eggs. Termiticides are formulated to eradicate termites. Repellents are substances that ward off bugs based on taste or odor. Algicides either kill or suppress the growth of algae. Chemosterillants are substances that induce sterility in insects, preventing reproduction.

2.4 Classification of pesticides based on mode of entry:

1. Systemic pesticides: are absorbed and transported by plants and animals to untreated tissues. Examples include glyphosate and 2, dichlorophenoxyacetic acid.
2. Non systemic or contact pesticides: these act on target pests upon contact. Examples include diquatdibromide and paraquat.
3. Fumigants: create vapour, entering pests through the trachea, potentially killing them
4. Stomach poisons like malathion, enter pests body through the trachea, potentially killing them.
5. Repellents don’t kill but deter pests by being unpleasant, interfering with their ability to locate groups.

2.5 Classification of pesticides based on mode of action: Based on diverse mode of action (and mechanism) the pesticides are of following types:

1. Physical poison: the direct physical impact of these causes insect mortality.
2. Respiratory poison: Inactive chemical substances affecting respiratory enzymes.
3. Inhibition of chitin: compounds that impede the synthesis of chitin in pests.
4. Protoplasmic poisons: Induce protein precipitation within pests.
5. Nerve poison: Chemicals that block the transmission of impulses in insects.

2.6 Classification based on sources of origin: According to this there are two categories: bio-pesticides and chemical pesticides. Chemical pesticides such as organochlorine, organophosphate, carbamate and pyrethroid pesticides, are further categorized based on their chemical composition. Bio-pesticides originate from natural sources like plants, animals microbes including bacteria, viruses, fungi and nematodes. They are grouped into three categories.

a) Microbial pesticides: produced by microorganisms like fungi, bacteria and protozoa, these pesticides kill insects by releasing poisons or infecting them

b) Plant incorporated pesticides: Naturally produced by plants, they involve genetic engineering to insert genes for pesticide production. The resulting plant and its genetic material are termed plant integrated protectants.

c) Biochemical pesticides: comprising natural compounds with non toxic pest control processes, examples include insect sex pheromones and fragrant plant extracts.

Understanding the distinctions among these categories is essential for farmers and agricultural practitioners to deploy the most effective and sustainable pest control strategies.

3 Agricultural pesticides, pesticide usage and occupational exposure

An analysis of global trends in pesticide application reveals dynamic patterns shaped by variations in regions and crops. Different geographical areas exhibit diverse agricultural landscapes, leading to variations in the types and amounts of pesticides utilized. The choices in pesticide application are influenced by factors such as climate, crop types, and pest prevalence. Certain regions with intensive monoculture practices may rely more heavily on specific pesticides to protect a singular crop, while others with diverse agricultural systems might adopt a broader spectrum of pest control measures. Amidst these trends, there is a growing recognition of the importance of Integrated Pest Management (IPM) strategies in fostering sustainable agriculture. IPM emphasizes a holistic approach, combining biological, cultural, and chemical control methods to manage pests effectively. By integrating various tactics, IPM seeks to minimize the environmental impact of pesticide use, mitigate resistance development in pests, and promote long-term agricultural sustainability. The analysis of global pesticide trends and the adoption of IPM emphasize the need for region-specific and crop-specific approaches to strike a balance between pest control efficacy and environmental stewardship in agriculture.

Occupational contact with pesticides emerge directly in the course of product manufacturing, during transportation, storage, user preparation and application encompassing re-entry into treated fields, harvest, and equipment cleansing. Within the agricultural domain, the primary entry of pesticides into the body is through dermal contact, subsequently followed by respiratory and oral routes. Inhalation exposure primarily occurs during fumigation, the formulation process or application in closed settings. The scrutiny of occupational exposure predominantly centers on farmers, farm labourers and workers in the pesticide manufacturing industry, although para-occupational and residential exposures also demand attention.

4 Environmental impact of pesticides

The examination of the ecological consequences of pesticide use reveals a complex web of impacts, extending beyond targeted pests to affect non-target species, soil health, and water quality. Pesticides, while designed for specific pests, often lead to unintended consequences by harming beneficial organisms. Non-target species, including pollinators and beneficial insects, can suffer population declines, disrupting ecosystems and diminishing biodiversity. Prolonged pesticide use can also compromise soil health by affecting essential microbial communities, vital for nutrient cycling and plant growth. Moreover, pesticides can contaminate water sources, leading to adverse effects on aquatic ecosystems and water quality. Case studies provide tangible illustrations of pesticide-induced ecological disruptions. Instances of bee colony collapse linked to neonicotinoid insecticides highlight the far-reaching impact on pollinators crucial for agriculture. Soil degradation due to the persistent use of herbicides exemplifies the long-term consequences on agricultural ecosystems. Additionally, contamination of water bodies, as observed in instances like the runoff of atrazine affecting aquatic organisms, emphasizes the need for a careful and informed approach to pesticide use. This study emphasizes the importance of adopting sustainable and ecologically sensitive pest management practices to mitigate the broader ecological consequences associated with widespread pesticide application.

5 Pesticides in food residues

The investigation of pesticide residues in food products is a critical aspect of ensuring food safety and protecting human health. Pesticides, when used in agriculture, can leave residues on crops, and their presence in food raises concerns about potential health implications. Continuous monitoring and analysis of pesticide residues in various food items are essential to assess exposure levels and potential risks for consumers. Studies have shown that prolonged exposure to certain pesticides may have adverse effects on human health, ranging from chronic illnesses to developmental issues, making the study of pesticide residues a matter of public health significance. In response to these concerns, regulatory measures and limits have been established to ensure food safety. Governments and international organizations set maximum residue limits (MRLs) for pesticides in various food products, based on scientific assessments of potential health risks. Rigorous testing and adherence to these limits aim to protect consumers and reduce the risks associated with pesticide residues in the food supply chain.

6 Human Health Risks

The analysis of the association between pesticide exposure and health issues reveals a complex interplay between agricultural practices and public health. Pesticides, while indispensable for crop protection, pose risks to both acute and chronic human health. In 1990, World Health Organization estimated one million unintentional pesticide poisoning and 20,000 deaths yearly. Despite increased pesticide use, there’s still no current global overview after 30 years. Pesticide ingestion is asserted to be the most common method of suicide in certain countries. Acute toxicity can result from high short-term exposure and may manifest as immediate symptoms such as nausea, dizziness, and skin irritation. Chronic exposure, often due to prolonged low-level contact, has been linked to a range of health issues, including respiratory problems, neurodevelopmental disorders, and certain cancers. Several studies suggest exposure to organochlorine, pyrethroid, organophosphate poses risk for the development of mental disorders, especially depression. Agricultural workers, in particular, face significant occupational hazards, as they are at the forefront of pesticide application. Direct contact during handling and spraying, along with inhalation of pesticide fumes, puts them at risk of acute poisonings and long-term health effects. Additionally, communities residing near to agricultural areas may face indirect exposure, raising concerns about potential health impacts. Vulnerable populations, including children, pregnant women, women of child bearing age, the elderly and those with health issues are more susceptible to pesticide exposure. Hence, a special attention should be given to these groups due to their increased risk of adverse health effects. Excessive pesticide exposure is linked to challenges in pregnancy, infertility, early menopause, endometriosis, liver and kidney issues and allergic reactions. For pregnant women, research suggests a connection between prenatal pesticide exposure and congenital malformations, abortions, low birth weight and potential childhood issues like early puberty and menarche. Some organochlorine pesticides have been related to breast cancer in postmenopausal women. Additionally, it is associated with psychiatric disorders and cognitive disturbances. Exposure to pesticides in the workplace has been linked to a higher risk of various health issues, including cancer, mental illness, endocrine disorders and autoimmune pathologies. Certain pesticides can disrupt female hormonal function, potentially leading to adverse effects on the reproductive system, specifically the ovarian cycle. Exposure to these pesticides may be linked to disturbances in the menstrual cycle, decreased fertility, prolonged time-to-pregnancy, spontaneous abortion, stillbirths and developmental defects. Several studies have investigated the respiratory toxicity of pesticides in vitro and in animals. Hexachlorobenzene exposure in rats led to airway inflammation and bronchial hyperreactivity. Bipyridyl herbicides like paraquat and diquat are recognized lung toxicants due to reactive oxygen species (ROS) production. Folpel (Phthalimide fungicide) demonstrated cytotoxicity on human bronchial cells, generating ROS within the first hour of exposure, hinting at a potential link to inflammatory respiratory diseases. The analysis of these associations highlights the need for strict safety measures, protective equipment, and comprehensive training for agricultural workers.

7 Pesticide resistance

The exploration of the development of resistance in pests to commonly used pesticides is significant challenge in modern agriculture. Prolonged and widespread use of specific pesticides leads to the emergence of resistant pest populations, diminishing the efficacy of pest control measures. The mechanisms of resistance often involve genetic adaptations in target pest species, allowing them to survive exposure to once-lethal pesticides. To address this issue and promote sustainable pest management, strategic measures are imperative. Integrated pest management (IPM) combines various strategies, including biological control, Crop rotation and diversification of pest control methods are crucial to minimize environmental impact. By employing a variety of control measures, including biological control agents, cultural practices, and judicious use of pesticides, the selection pressure for resistance can be reduced. Additionally, the judicious use of pesticides involves rotating different chemical classes to minimize the risk of resistance development. Continuous monitoring of pest populations and adapting control strategies based on observed resistance patterns are integral to successful pest management. This comprehensive and adaptive approach not only mitigates the development of resistance but also maintain long-term sustainability in agriculture by preserving the effectiveness of pest control measures.

8 Regulatory framework and challenges

Global pesticide regulations vary due to diverse farming practices, environmental factors and public health concerns. Numerous countries and international bodies have established regulatory frameworks to regulate the production, sale, and application of pesticides. These regulations typically include guidelines on permissible pesticide types, application methods, and allowable residue levels in food products. Challenges in implementing and enforcing these regulations, however, are clear. One fundamental challenge lies in the diversity of regulatory standards across different countries, leading to variation in pesticide management practices. Limited resources and capacity in some regions hinder effective enforcement, while in others, strict regulations may face challenges in balancing agricultural productivity with environmental and health protection. Monitoring and regulating the global trade of pesticides also present difficulties, especially with the movement of products across borders. Additionally, the dynamic nature of the agricultural industry and the rapid development of new pesticides can outrun regulatory adjustments, necessitating timely updates. Overcoming these challenges requires collaborative efforts among countries, international organizations, and industry stakeholders to harmonize standards, enhance regulatory capacities for sustainable and safe pesticide use globally.

9 Alternative and sustainable practices

Sustainable alternatives to pesticides are crucial for environmentally conscious agriculture. IPM takes a holistic approach by combining strategies like biological control, crop rotation and targeted pesticide use to minimize environmental impact. Biological control methods, which involve the introduction of natural predators or the use of microbial agents to control pests, offer a sustainable and targeted approach. Crop rotation disrupts pest life cycles by alternating the types of crops planted seasonally, promoting soil health. Cover crops, planted during off seasons, control weeds and enhance soil structure without the need for herbicides. Biopesticides emerge as an excellent ecofriendly substitute for chemical counterparts, fostering sustainable agricultural practices and mitigating pollution. Encouraging the formulation and application of bio pesticides is crucial for promoting environmentally friendly agriculture and safeguarding against the negative impact of chemical pesticides. Organic farming practices, emphasizing natural fertilizers and avoiding synthetic chemicals, contribute to pest control by fostering resilient ecosystems. Agroforestry integrates trees and shrubs into agricultural landscapes to provide habitat for beneficial insects and enhance biodiversity. Beneficial insects such as ladybugs and parasitic wasps contribute to pest control. Trap crops attract pests away from main crops, reducing damage. Selective breeding creates crop varieties resistant to pests, minimizing the need for chemical interventions. Companion planting involves strategically placing crops to deter pests naturally. These sustainable practices collectively contribute to an eco-friendlier agricultural system, reducing the environmental impact associated with traditional pesticide use. Precision agriculture, incorporating technology and data analytics, allows for more targeted and efficient use of inputs, including pesticides. Research and innovation play a pivotal role in developing and advancing these sustainable pest management practices. Ongoing research & scientific efforts aim to refine biological control strategies, optimize organic farming techniques, and enhance precision agriculture tools. The integration of cutting-edge technologies, such as drones and sensors, allows for precise monitoring and application of pest control measures. Ongoing studies enable the identification of effective biological agents & development of organic pesticides. Continuous innovation ensures farmers have access to reliable, environmentally friendly tools, ultimately reducing the ecological impact of pest control methods. The role of research is not only in mitigating the immediate impacts of pests but also in fostering long-term sustainability by minimizing environmental harm and promoting ecosystem health. This review also emphasizes the importance of a varied and innovative approach to pest management, where ongoing research drives the evolution of sustainable practices for the benefit of agriculture and the wider environment.

10 Future directions and research gaps

The identification of areas requiring further research is important for enhancing our understanding of the complex impacts associated with pesticide use. There is an urgent need for comprehensive studies of the long-term ecological consequences, including the effects on biodiversity, soil microbiota, and aquatic ecosystems. Research should also focus on assessing the chronic health implications of prolonged pesticide exposure on both agricultural workers and consumers. Additionally, understanding the dynamics of pesticide residues in air and water, is essential for evaluating their broader impact. Recommendations for future studies include exploring the synergistic effects of multiple pesticide residues and understanding the potential growing risks. Moreover, investigating strategies for alleviating resistance in pests and identifying alternative pest control methods that are both effective and environmentally sustainable should be a research concern. The potential for developing safer pesticide alternatives, whether through innovative chemical formulations, biological control agents, or precision application technologies, offers a promising path for future research. Scientists are constantly working on pesticide formulations to make them more targeted & less harmful to non target organisms. They are exploring new delivery systems, such as nanoparticles & encapsulation technologies to increase pesticide efficiency and reduce environmental impacts. These alternatives should be thoroughly assessed for efficacy, environmental impact, and their potential to reduce risks to human health. A collaborative effort towards advancing research in these identified areas is fundamental for creating evidence-based policies that promote sustainable and safe pesticide practices in agriculture.

11 CONCLUSIONS

In conclusion, it becomes evident that the benefits of pesticides in agriculture are substantial, contributing to increased crop yields and global food security. However, a critical aspect that emerges is the necessity for balancing these benefits with careful consideration of environmental and health implications. Pesticides, while integral to modern farming, pose challenges such as ecological disruptions, water contamination, and potential health risks for both agricultural workers and consumers. Striking a balance necessitates an approach that acknowledges the need for pest control while minimizing adverse effects. This calls for a multidisciplinary and collaborative strategy, involving scientists, policymakers, farmers, and the public. A strong collaboration lead to development of innovative and sustainable pest management practices, incorporating alternative methods, precision technologies, and an enhanced regulatory framework. By integrating diverse expertise, we can navigate the complexities of pesticide use, ensuring that agriculture remains productive simultaneously safeguarding ecosystems and human well-being. Such a holistic approach is vital for addressing the challenges associated with pesticide use and directing agriculture towards a more sustainable and environmentally conscious future.

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