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Pesticides Uses, Environmental Consequences and their Potential Mitigation Approaches: An Overview

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ABSTRACT

Pesticides are chemical agents employed to ward off plant diseases and weeds, playing a pivotal role in enhancing both the quality and quantity of agricultural produce. However, due to a prevalent lack of awareness among farmers regarding their proper application, these chemicals often negatively interact with the environment. They not only alter the intrinsic properties of natural substances but also pose detrimental effects. Once absorbed by the soil, pesticides can enter the food chain, impacting both plant and animal life, leading to potential acute or chronic health issues among individuals across age groups. Moreover, when introduced into aquatic ecosystems, they bring in a slew of toxic materials, contaminants and heavy metals, thereby endangering aquatic life. This review delves into the harmful characteristics of various pesticides, their environmental repercussions and potential mitigation techniques. Given the observed negative effects on human health, flora and fauna, there's an urgent need to control their synthesis, usage and release on a large scale.

Keywords: Environmental impacts; Human health; Pesticides; Remediation techniques; Sources of pesticides

INTRODUCTION

Pesticides are chemical compounds designed to eradicate or deter living organisms deemed harmful. Depending on their application and characteristics, they can be categorized into several classes, such as bactericides, algicides, herbicides and more. Those with carbon rings include categories like organophosphorus, carbamates and pyrethroids, among others. During Pakistan's green revolution era, there was a significant emphasis on developing benign pesticides. This was to counteract the myriad of insects and plant pests that threatened the quality and volume of global food supplies. All the pesticides produced, agriculture consumes approximately 85%, with the remaining used for public health measures such as controlling vector-borne diseases, managing overgrowth of plants and in industries for safeguarding equipment and food packaging from pests. It's estimated that a staggering 5.6 billion pounds of pesticides are used globally every year, showing an alarming rise. Europe accounts for nearly 45% of this consumption, the USA 25% and the remaining 25% is spread across the rest of the world. Within this context, China and the USA lead the consumption, while Pakistan stands as a prominent consumer in South Asia [1].

Pesticides encompass a diverse array of compounds tailored for various agricultural needs such as herbicides, insecticides, fungicides and plant growth regulators, among others. Their specific use, origin and toxicity vary based on their intended application and formulation. Such variety and widespread

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application have elevated global concerns regarding pesticides. This is primarily because those involved in agriculture, as well as communities adjacent to farming areas, face direct and indirect exposure during processes like treatment, cleaning and storage of agricultural goods. Ironically, even pesticides deemed effective not only affect the broader ecosystem's flora and fauna but can also inadvertently harm the very organisms they're designed to protect. The push for new and potent pesticides arises from the mounting global food demand. Without them, vital crops like fruits, vegetables and cereals become vulnerable to pests and related diseases, undermining both the volume and quality of food. However, numerous studies, such as those by Oliveira et al. and Trudi et al., have documented the detrimental effects of pesticide usage on the environment, plants and animals [2].

LITERATURE REVIEW

Varieties of Pesticides in Application

Pesticides can be grouped based on various factors such as their chemical composition, how they work, functional aspects and levels of toxicity. As pointed out by Gracia, common categorizations based on application include fungicides, herbicides, insecticides and rodenticides. Delving into their chemical classifications, Amaral and Mnif et al., elucidate that pesticides fall under inorganic or organic categories.

Inorganic pesticides comprise elements and compounds like copper sulphate, ferrous sulphate, sulphur and lime. On the other hand, organic pesticides, known for their potential long-term effects, have a more intricate structure. Kim et al., emphasized the possible severe chronic impacts of organic pesticides. Based on their chemical structures. Zhang et al., further classify organic pesticides into several types, including chlorohydrocarbon insecticides, carbamate insecticides, organophosphorus insecticides, metabolites, synthetic pyrethroid insecticides, synthetic urea herbicides, benzimidazole nematicides, triazine herbicides and metal phosphide rodenticides [3].

Global pesticide consumption is projected to exceed 4 million tons annually, as highlighted by faostat. This significant use is due to the sporadic and largely unregulated distribution of these chemicals across the globe. It's worth noting that European nations consume about a third of the world's pesticides, while North America accounts for a quarter. Breaking down North America's pesticide usage, herbicides represent almost half, followed by insecticides at 19%, fungicides at 13% and a diverse mix of other materials making up the remaining 22% [4].

Insecticides are particularly dominant in burgeoning agricultural sectors. Crops and livestock, for instance, consume a significant 74% of the world's insecticides every year, with forestry using just 1%. Certain pesticides, such as Dichloro Diphenyl Trichloroethane (DDT) and lindane, are extensively used in Scandinavian and Asian countries for agricultural purposes. Additionally, DDT is prominently used to combat mosquito vectors associated with diseases like tse-tse fly and malaria, especially in South Africa and other tropical nations. Pesticide usage varies widely based on crop types. For example, corn, cotton and soybean crops are the primary consumers of herbicides globally, with the U.S. accounting for 75% and the rest of the world the remaining 25%. Meanwhile, plantations often rely on insecticides and vegetables and vineyards are major consumers of fungicides [5].

Pesticides can be grouped based on their chemical composition into categories such as organophosphates, pyrethroids, organochlorines, carbamates and chlorines. Depending on their composition, some pesticides dissolve in water, while others are more soluble in organic solvents. Typically, these chemicals act by targeting the nervous system of pests, leading to their eradication. When used as directed, they are generally considered safe for non-target organisms.

DISCUSSION

How Pesticides Interact with the Environment

After being applied to target plants, pesticides often find their way into the soil. They can migrate within the soil, usually through water, *via* processes such as transport or degradation. This degradation in the environment can result in the formation of new chemical compounds. Furthermore, these chemicals can move beyond their intended locations to areas without vegetation through mechanisms like leaching, adsorption, spray drift, volatilization and runoff, depending on their characteristics. Certain pesticides, such as organochlorine compounds including DDT, might have low immediate toxicity but can have long-term effects. They can linger in plant tissues, causing sustained damage to growth and physiological processes. Meanwhile, organophosphate pesticides may have minimal short-term effects, but if they remain in mammals for extended periods, they can cause adverse impacts [6].

Pesticides can persist in the environment for extended periods, with their duration often determined by the half-life of their constituent compounds. On average, a pesticide has a half-life of about fifteen days. Many researchers have noted that about 50% of a pesticide can remain fifteen days after its application to target plants. Furthermore, a quarter of the original amount (or 25%) can still be present for an additional thirty days. As the lifespan of these pesticides extends, their mobility in the soil and surrounding environment tends to increase. Various factors influence the persistence of pesticides in the environment, including photo-degradation, microbial degradation and chemical degradation. The extent to which these pesticides break down in the environment hinges on the chemistry of the compounds, environmental conditions and circulation patterns. Kerle, et al., emphasized that the movement of pesticides in the environment can be influenced by factors such as sorption, solubility, vapor pressure, as well as conditions like weather, canopy cover, topography, ground cover, soil texture, organic matter and soil structure. Using models to track the presence of pesticides can offer valuable insights into understanding their fate and impact on the environment. These models can help determine the rate and frequency of pesticide degradation, providing data that supports decisions on how to effectively remove them from the environment [7].

Effects of Pesticides on Flora, Fauna, Terrestrial Ecosystems, Aquatic Systems and Atmosphere

The benefits of pesticides can often be overshadowed by their detrimental effects, particularly when they contaminate our food chain and drinking water sources, as outlined in Table 1. Health concerns primarily arise from consuming food tainted with hazardous pesticides. Pesticides often impact non-target species in the air, water and soil. People can encounter pesticide toxicity through inhalation, ingestion or absorption. Prolonged exposure can lead to severe health issues, such as neurological disorders, hormonal imbalances, immune system malfunctions and blood-related diseases. Additionally, pesticides can adversely affect plant growth, germination, development, biochemical pathways, yields and certain antioxidant enzymes, as detailed in Table 1. When plants absorb these chemicals, it can disrupt their growth by inducing metabolic imbalances.

Table 1: Effects of pesticides on plant health.

S. No	Impact	Reference
1	Affect plant growth, germination and development, variations in biochemical passageways, yield and some antioxidant enzymes	Parveen, et al.
2	Affect the physiology of crop Gimenez	Moolhuyzen, et al.
3	Affect the plant growth and cause metabolic disorders	Sharples, et al.
4	Block the photosystem II in photosynthesis pathway	Del Valle, et al.
5	Affect the photosystem II badly in chloroplast	Devine, et al.
6	Reduced chlorophyll a, b and total chlorophyll along with carotenoid contents in the leaves of pepper	Tort and Turkyilmaz
7	Decrease in the supply of photosynthesis in the roots	Alonge
8	Decrease in photosystem II and whole chain activities	Mathur and Bohra
9	Reduced the growth of root and shoot	Mishra, et al.
10	Caused nearly complete inhibition of growth in maize plants	Murthy, et al.
11	Decrease in pods and seed yield of rice crop	Mugo
12	Decrease in the growth and yield of barley plants	Boonlertnirun, et al.
13	Changes in vegetation growth, death of plant, decrease in reproduction capability, reduced fitness and detrimental, economic and ecological impacts	Altman
14	Mutations in crop genes and changes in uptake of nutrients, transport of nutrients and metabolism of crops	Marrs, et al.

Pesticides can negatively impact both human and animal health in various ways, as detailed in Table 2. Humans can be exposed to pesticides by inhaling air, dust or vapours laden with these chemicals, consuming tainted food and water or direct skin contact. When applied to food crops, pesticides can leach into the soil and water, contaminating them. Additionally, pesticide drift can pollute the air. Interactions with these contaminated elements pose risks when humans come into contact with them in their environment. Furthermore, individuals face potential hazards when handling and using pesticides, including risks during equipment cleaning, storage and the contamination of water, clothing and food [8].

Table 2: Effects of pesticides on animal and human health.

S. No	Impact	Reference
1	Cause of chronic diseases which effect nervous system, reproductive system, cardiovascular system, renal system and respiratory system	Mostafalou and Abdollahi
2	Cause headaches, skin rashes, nausea, body ache, poor concentration, dizziness, cramps, panic attacks, impaired vision, birth defects, production of benign or malignant tumors, toxicity in fetus, mutations, nerve disorders, genetic changes, blood disorders, reproduction effects and endocrine disruption. In animals' pesticides cause potential carcinogens, reproductive toxins, neurotoxins and immune toxins. Some studies show the development of neurodegenerative diseases	PAN

Pesticides have noticeable effects on the soil ecosystem. Soil often acts as a long-term storage medium for pesticides, especially those with organic carbon, due to its filtering capacity, buffering nature and high degradation potential, as highlighted in **Table 3**. Pesticides can enter the soil both directly and indirectly. The direct introduction occurs when they are applied in fields, while indirect methods include accidental spillage, leaks or runoff from plant surfaces. Indiscriminate use of pesticides can lead to soil contamination, adversely affecting non-targeted organisms, which can disrupt soil biomass and harm vital microorganisms like bacteria, earthworms and fungi, as detailed in Table 4. Such non-targeted organisms play essential roles in maintaining soil fertility and aiding pesticide degradation. Their metabolic processes can be harmed by pesticides. Over-reliance and excessive use of pesticides by farmers to combat pests and diseases can negatively impact soil health [9].

Table 3: Effects of pesticides on terrestrial ecosystems.

S. No	Impact	Reference
1	Damages and reduction of soil biomass	Azam, et al.
2	Damages in the local metabolism	Kale and Raghu
3	Contaminate the soil nutrients and cause adverse effects on humans and environment	Oberemok, et al.
4	Cause acute poisoning for microbial biomass	Yadav and Devi, et al.
5	Pollute surface and water bodies	Yadav and Devi
6	Decline in the soil fertility	Jia and Conrad

Pesticides can have detrimental effects on aquatic ecosystems, as outlined in **Table 4**, by polluting both surface and groundwater. Contamination of groundwater can significantly alter water quality. Even with regulated use, traces of pesticides can still be detected in drinking water, posing a risk of human exposure. Water, essential for life, faces increasing pollution due to various natural and human-induced activities. The toxicity of pesticides in aquatic environments is influenced by factors such as exposure levels, immune reactions, assay methods, stress thresholds and the inherent toxicity of the pesticide. The harmful effects of pesticides are further amplified when they are part of a composite mixture containing multiple components [10].

Table 4: Effects of pesticides on aquatic ecosystem.

S. No	Impact	Reference
1	Create pollution in aquatic ecosystem and cause ecological damages which in turn damage the natural habitat of fishes in water bodies	Macneale, et al.

2	Damages of aquatic life which includes fish and plants by reducing dissolve oxygen levels leading to changes in physiology of aquatic life	Mahmood, et al.
3	Damage of aquatic plants, animals and marine populations	Helfrich, et al.

Remediation Techniques for Removing Pesticides

The escalating use of pesticides has sparked concerns about their removal from the environment. Numerous methods have been developed to address the contamination in soil, water, air and food. Direct measures to reduce pesticide residue in food include washing, peeling, cooking and blanching. However, these measures may not entirely eliminate pesticides due to their resilience and lingering nature. Biological and chemical-based remediation techniques are deployed for reclaiming pesticide-laden soil and neutralizing hazardous wastes. Table 4 details various technologies and plants employed for pesticide remediation. One such method is the Contaminant-Immobilization Technology (CIT), an *in-situ* approach offering a cost-effective solution for restoring pesticide-contaminated soil in a relatively short timeframe. This technique leverages adsorption, potentially harmful to non-targeted organisms. Minimal treatments are employed as carbonate materials, predominantly sourced from biological entities, are processed using organically active residues.

Another widely-used method is separation technology. This involves the use of solvents and synthetic surfactants to extract contaminants from a sludge medium. The specific remediation strategy might encompass solvents, synthetic surfactants, soil flushing, cyclodextrins and biosurfactants. The choice of solvent depends on the specific pollutant being addresse. The Fenton advanced oxidation process is employed to target organochloride pesticides like DDT. Recognized for its tenacity and significant bioaccumulation, DDT poses severe environmental threats. Nevertheless, solely relying on this process does not guarantee the comprehensive elimination of DDT and related chlorinated toxicants. Achieving optimal removal necessitates considerable usage of ferrous salts. Additionally, the introduction of acids for DDT degradation tends to acidify and erode the soil, subsequently reducing its fertility [11].

Another promising technique is the supercritical fluid extraction, which is effective in extracting polycyclic aromatic hydrocarbons from polluted subcritical water. This method leverages microorganisms for bioremediation, specifically targeting contaminants like trinitrotoluene and polychlorinated biphenyls. Electro-kinetic remediation employs zero-valent iron nanoparticles to shield the environment from pollutants, including Polychlorinated Biphenyls (PCBs) and chlorinated solvents. While these nanoparticles effectively detoxify contaminants, their high reactivity presents a limitation to this approach.

Photocatalysis stands as a promising approach for pesticide degradation, utilizing various semiconductors, from metal oxides and sulphides to substrates in composite materials. Notable variations include titanium oxide, zinc sulphide, G-C3N4 and graphite-based photocatalysis. In the realm of biological solutions, phytoremediation offers an economical method harnessing the power of the sun. This technique leverages specific plant species adept at extracting or reducing environmental pesticide levels, with removal efficiencies ranging between 0% to 70%. Through mechanisms like phytodegradation, phytoextraction and rhizodegradation, phytoremediation emerges as an environmentally-friendly and cost-effective strategy [12].

Algae, especially microalgae, are powerful agents in pesticide remediation. These photosynthetic organisms efficiently transform solar energy into chemical energy, making them swift and efficient nutrient transporters. Notably, microalgae excel at bioaccumulating pesticides, turning organic pollutants into energy source. Their robust nature and adaptability to varying environmental conditions further amplify their effectiveness. Bacterial degradation presents another sustainable and cost-effective option for pesticide removal. Specific bacteria strains, such as those from *Arthrobacter*, *Flavobacterium* and *Burkholderia*, have demonstrated notable pesticide degradation capacities. These microorganisms metabolize pesticides into essential nutrients, releasing environmentally benign byproducts like CO_2 and H_2O. This bacterial efficiency is significantly amplified in the presence of specific anions.

Lastly, mycoremediation enlists fungi as a biological response to the pesticide dilemma. As eukaryotic organisms, fungi can assimilate and detoxify pollutants from various ecosystems. Through their transformative capabilities, fungi can neutralize pesticides, rendering them into non-toxic compounds for further microbial degradation. Their approach targets the functional groups of pesticides, inducing chemical alterations and ensuring rapid degradation through processes like hydroxylation, dechlorination and esterification [13].

CONCLUSION

Pesticides are chemicals predominantly utilized in the agricultural sector to manage organisms that might harm crops. While they offer considerable advantages, they also present significant environmental challenges. These compounds can harm our environment through contamination and are linked to various health complications. Addressing the residue of pesticides in the environment has recently emerged as a global priority. A myriad of methods has been established to mitigate the effects of pesticides and research is ongoing to develop even more efficient solutions. By leveraging plants, animals and specific chemical treatments, we can significantly reduce pesticide residues in soil and water. A judicious approach to pesticide application can safeguard our environment from its detrimental effects.

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