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Review

PESTICIDES FROM PUBLIC HEALTH PERSPECTIVE: THREATS, RISKS AND PREVENTIVE STRATEGIES

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Abstract: *Pesticides are chemical substances widely used in modern agriculture to enhance crop productivity and combat pests. However, the uncontrolled and widespread use of pesticides poses significant threats to both the environment and human health. This study examines the public health impacts of pesticides, focusing on exposure pathways, health effects, and prevention strategies. The study highlights that exposure to pesticides primarily occurs through inhalation, dermal contact, and the consumption of contaminated food and drinking water, emphasizing that vulnerable groups such as children, pregnant women, and agricultural workers are particularly at risk of experiencing severe health issues. In addition to acute poisonings, long-term low-dose exposure has been scientifically linked to chronic diseases, including cancer, neurological disorders, and endocrine disruptions. The study also elaborates on primary, secondary, and tertiary prevention strategies within the framework of public health and offers recommendations regarding alternative agricultural practices and regulatory measures. In this context, effective monitoring, education, the promotion of alternative methods, and the enhancement of public awareness are necessary to reduce the harmful effects of pesticides.*

Keywords: *Pesticide, public health, food safety, organic farm, acute poisoning, chronic exposure*

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1. Introduction

Pesticides are chemical or biological substances used to kill, control, or repel harmful organisms. In recent years, the use of pesticides has significantly increased in order to meet the growing global demand for food [1, 2]. However, the indiscriminate use of these chemicals poses serious threats not only to pests but also to human health, the environment, and ecosystems [3, 4]. These substances may be applied directly or indirectly to plants, seeds, soil, or water. Based on the type of pests they target, pesticides can be classified as follows:

- **Insecticides**: Effective against insects
- **Herbicides**: Destroy weeds
- **Fungicides**: Target fungal pathogens
- **Rodenticides**: Eliminate rodents such as rats and mice
- **Others**: Including acaricides, bactericides, nematicides, etc.

Some pesticides are lipophilic (fat-soluble), which enables them to accumulate in body fat and potentially lead to long-term toxic effects [5, 6, 7]. Their widespread use in both agricultural and domestic environments represents a significant threat to public and environmental health. Due to their persistent nature, these chemicals can remain in the environment for long periods and gradually enter

the food chain [8]. The health impacts of pesticides today are not limited to acute poisoning; numerous scientific studies have linked them to a broad range of chronic diseases, including cancer, neurological disorders, congenital anomalies, endocrine disruption, and reproductive health issues [2, 9, 10].

Although pesticide use continues to rise, inadequate monitoring of residues and limited adoption of alternative pest control methods have intensified the problem. While many countries—particularly within the European Union—have implemented stricter pesticide regulations, public health risks remain high in developing and underdeveloped nations due to insufficient enforcement and a lack of public awareness [11, 12]. Pesticide residues have been detected in a variety of foods and beverages, including fruit juices, wine, water, snacks, and poultry feed. Research has shown that simple washing and peeling are not enough to remove these residues. Furthermore, the detection of pesticide residues in breast milk indicates the possibility of fetal exposure. Collectively, these findings indicate that pesticides represent one of the most pressing public health challenges of our time [13, 14].

2. Routes of Exposure

Pesticide exposure varies depending on an individual's lifestyle, occupation, living environment, and consumption habits. The level and duration of exposure are among the primary factors influencing health. Agricultural workers, individuals living in rural areas, and children are particularly at higher risk of exposure to these substances [9, 15].

In general, pesticide exposure occurs through four main routes: inhalation, dermal contact, ingestion through food, and contaminated drinking water.

2.1. Inhalation Exposure

Most pesticides are applied in agricultural settings via spraying techniques. During this process, aerosols and vapors released into the air can remain suspended and disperse throughout the environment. Not only applicators but also nearby individuals can be exposed to these airborne pesticide particles through inhalation [16].

It has been observed that pesticides can be carried several hundred meters under windy conditions [3]. Numerous studies have reported a high prevalence of acute respiratory illnesses and asthma-like symptoms among agricultural workers [17].

2.2. Dermal Exposure

Dermal contact represents one of the most common exposure routes, particularly for agricultural workers and pesticide applicators. During application, pesticides can be absorbed through exposed areas such as the hands, arms, and face. Many pesticides, due to their lipophilic nature, can easily penetrate the skin barrier [17, 18].

In the absence of appropriate protective equipment, pesticides have been documented to cause skin irritation, redness, and systemic absorption, and in some cases, serious poisoning [7, 19, 20].

2.3. Dietary Exposure

The primary route of pesticide exposure for consumers is through the ingestion of fruits and vegetables containing pesticide residues. If the pre-harvest interval is not adequately observed after pesticide application, residue levels in the produce may increase. High-risk products include strawberries, peppers, lettuce, and grapes [21, 22].

2.4. Waterborne Exposure

Some pesticides can contaminate surface and groundwater sources, thereby polluting drinking water supplies. This represents a significant health risk, especially for populations living in regions

with intensive agricultural activity. The magnitude of this risk depends on the solubility, half-life, adsorption capacity, and biodegradability of the pesticide compounds [23].

2.5. Determinants of Exposure

The health impact of pesticide exposure must be evaluated considering the type of pesticide, dosage, duration of exposure, and individual factors such as age and health status. For instance, children are more vulnerable due to higher food intake per body weight and immature detoxification systems [15, 16].

Moreover, certain pesticides can cross the placental barrier during pregnancy and directly affect fetal development [24].

3. Acute and Chronic Health Effects

Health problems caused by pesticide poisoning can be examined in two groups: acute (short-term exposure to high doses) and chronic (long-term exposure to low doses). Acute effects are more commonly seen in groups that are in close contact with pesticides, such as agricultural workers and spraying personnel. Chronic effects, on the other hand, are more widespread in the general population and often progress insidiously without noticeable symptoms. While acute effects are often dramatic and prompt immediate clinical attention, chronic effects frequently remain unnoticed until irreversible damage has occurred [2, 9, 11, 25].

3.1. Acute Health Effects

Acute pesticide poisonings generally occur as a result of short-term exposure to high doses during pesticide applications. They are most frequently encountered among agricultural workers. Especially in developing and underdeveloped countries, such poisonings are common due to the lack of protective measures such as masks and protective equipment [3, 9].

Acute toxic effects may appear within a few minutes to several hours after pesticide exposure. Poisoning affects not only peripheral muscarinic and nicotinic receptors but also the central nervous system. Symptoms of acute pesticide poisoning include nausea, vomiting, diarrhea, abdominal cramps, urinary incontinence, miosis, excessive salivation, lacrimation, bronchorrhea, bradycardia, hypotension, twitching, muscle paralysis, dizziness, confusion, seizures, coma, and respiratory failure. These effects can appear immediately upon exposure. Moreover, if not treated promptly and appropriately, life-threatening complications may occur, leading to death [8].

The severity of these symptoms depends on the dose and type of pesticide. The most common types of poisoning are associated with organophosphate and carbamate pesticides. Globally, approximately 3 million pesticide poisoning cases occur each year, with around 220,000 resulting in death. The vast majority of these cases are reported in low- and middle-income countries in Africa, Latin America, and Asia [3, 9].

Most deaths result not from occupational or accidental exposure via skin contact or inhalation, but from intentional ingestion in suicide attempts. Overall, the pesticide poisoning mortality rate has been decreasing as newer and safer pesticides are incorporated into global agricultural practices and more toxic pesticides are phased out. This effect has been clearly observed in Sri Lanka and China, where the number of pesticide-related suicides has dropped by over 70% in the last two decades [26].

According to data from the Turkish Ministry of Health, more than 5,400 acute pesticide poisoning cases were reported between 2018 and 2022. The majority of cases were observed in individuals working in the agricultural sector [27].

3.2. Chronic Health Effects

Chronic pesticide exposure occurs over a long period and usually at low doses; thus, symptoms develop slowly and are often noticed too late. However, the effects may be much more persistent and severe compared to acute poisonings [2, 11].

3.2.1 Cancer Risk Associated with Pesticide Exposure

Numerous epidemiological studies have shown significant associations between pesticide exposure and certain types of cancer such as prostate, leukemia, lymphoma, and breast cancer [25, 28]. Some pesticides can directly damage DNA, leading to mutations and tumor development [29].

In particular, studies on herbicides and insecticides have revealed an increased risk of colon and rectal cancer [30].

3.2.2 Neurological and Psychiatric Effects

The effects of pesticides on the central nervous system have been linked to depression, anxiety, cognitive decline, and Parkinson's disease [31, 32].

3.2.3 Endocrine System Disorders

Some pesticides are classified as endocrine-disrupting chemicals (EDCs). These chemicals can interfere with the functions of hormones such as thyroid, estrogen, and insulin. This can lead to health problems such as developmental delays, obesity, infertility, and thyroid diseases, particularly in children [33-35].

3.2.4 Reproductive and Developmental Effects

Pesticide exposure may increase the risk of reproductive problems such as decreased fertility in women, abnormal births, irregular menstruation, premature birth, miscarriage, stillbirth, congenital abnormalities, and low birth weight [36]. There are also studies showing that some pesticides reduce sperm quality and may cause infertility in men. Furthermore, pesticides that can cross the placental barrier may directly affect fetal development and lead to undesirable outcomes [37].

3.2.5 Effects on the Immune System

Some types of pesticides may suppress the immune system and increase susceptibility to infections. They have also been shown to be associated with autoimmune diseases [18]. Scientific studies have demonstrated that pesticides such as atrazine (ATR), organophosphates (OP), carbamates, and pyrethrins can impair the survival and growth of leukocytes by inducing apoptosis or cell cycle arrest and interfering with the specific immunological functions of immune cell types [38].

4. Global and Local Pesticide Usage Rates

According to FAO (2022) data, global pesticide use in 2021 was approximately 4.1 million tons, representing an increase of more than 60% compared to 1990. Several factors have contributed to this significant rise. One of the primary reasons is the widespread adoption of monoculture farming systems, which are more vulnerable to pest infestations. Additionally, the development of resistance to pesticides among pests has led to the need for increased application. Climate change has also played a role by creating conditions that favor the growth and spread of pest populations. Furthermore, high yield expectations and economic pressures have driven farmers to rely more heavily on pesticides to protect their crops and maximize production [12, 39].

The countries that use the most pesticides are China (approximately 1,800,000 tons), the United States (around 400,000 tons), and Brazil (about 380,000 tons) [12].

Active ingredients such as glyphosate, chlorpyrifos, and mancozeb are among the most commonly used pesticides globally [29].

Pesticide use in Turkey has shown a significant increase over the past 10 years. According to data from TURKSTAT and the Ministry of Agriculture and Forestry, approximately 62,300 tons of pesticides were used in 2023. This amount is nearly double the usage in 2010 [40].

In inspections conducted by the Ministry of Agriculture and Forestry, the issue of pesticide residues in food in Turkey is notable. In 2022, it was found that 7.6% of fruit and vegetable samples analyzed exceeded the maximum residue limit (MRL) [40]. The average pesticide use among European Union member countries is 3.5% [21].

In Turkey, Antalya is the province with the highest pesticide use, while Ardahan uses the least. The Mediterranean Region accounts for the highest pesticide use due to its diverse crop cultivation, whereas the Black Sea Region uses the least. In 2020, the most used pesticide groups in Turkey were fungicides (38.4%), herbicides (27.4%), and insecticides (23.0%), respectively. An examination of the top three provinces with the highest pesticide use reveals that fungicides were the most common in Antalya (38.3%) and Manisa (81.0%), while insecticides were predominant in Adana (65.2%) [41]

As of 2021, the average pesticide use per hectare in Türkiye was 2.26 kg. This amount is lower than the European Union average (3.20 kg/ha) but higher than the global average (1.07 kg/ha). While herbicides account for the largest share of pesticide use per unit area worldwide (21.92%), fungicides and bactericides have the highest share in the EU (43.18%) and in Türkiye (36.06%). This indicates that pesticide use in Türkiye is particularly concentrated on combating fungal and bacterial diseases [42].

To assess compliance with maximum residue limits (MRLs) of pesticides, the most commonly used methods include the QuEChERS extraction technique combined with LC-MS/MS or GC-MS/MS analysis. These methods allow for the simultaneous and highly sensitive detection of multiple pesticide residues. The results of such analyses play a critical role in identifying potential health risks when MRLs are exceeded and in ensuring consumer safety [43].

5. Strategies for Minimizing Pesticide Exposure

To mitigate the harmful effects of pesticides on human health and the environment, it is crucial to develop multifaceted protection strategies at individual, societal, legal, and political levels. In addition, it is imperative to promote sustainable and environmentally conscious agricultural practices as viable alternatives to traditional chemical control methods [2, 9, 44].

5.1. Primary Prevention: Preventing Exposure

At this level, the primary objective is to prevent pesticide exposure before it occurs, thereby safeguarding society from potential health risks:

5.1.1 Personal Protection Methods

The use of personal protective equipment (PPE) by pesticide applicators significantly reduces direct exposure. Equipment such as gloves, masks, and protective eyewear acts as a physical barrier against pesticide residues. Furthermore, compliance with hygiene and safety protocols by applicators plays a pivotal role in preventing exposure [3, 45, 46].

5.1.2 Food Cleaning and Preparation Techniques

Consumers can mitigate pesticide residues by thoroughly washing fruits and vegetables with abundant water, peeling products with peelable skins, and opting for organic produce. However, it should be noted that washing and peeling may not completely eliminate pesticide residues [47].

5.1.3 Education and Awareness Programs

The dissemination of educational programs has been shown to reduce pesticide application errors and poisoning incidents. Tailoring educational programs to specific target groups (such as farmers, children, and consumers) will be more effective. Social media campaigns can also play a significant role in raising awareness about pesticide use [48, 49].

5.1.4 Legal Measures and Inspections

The frequency and scope of inspections should be increased; residue analyses must be conducted routinely for both domestic and export products [21]. Additionally, legal authorities should enforce the prohibition or restriction of hazardous pesticides [9].

5.1.5 Alternative Practices

Organic farming represents a production model where the use of synthetic chemical pesticides is strictly prohibited. Pest management is accomplished through natural methods, with an emphasis on biological and physical interventions. The risk of pesticide residues in organic products is negligible. However, due to production costs and the challenges associated with inspections, continuous support for organic farming is essential [47, 50].

5.1.6 Biological Control

This method involves the use of natural predators of harmful organisms (such as predatory insects, parasitoids, etc.). For example, *Bacillus thuringiensis* is highly effective against lepidopteran larvae [51].

5.1.7 Digital and Technological Solutions

Advancements in agricultural technologies present significant opportunities for reducing pesticide use. These include disease and pest detection using sensors and IoT devices, as well as precision spraying through drone and GPS technology [52, 53].

5.2. Secondary Prevention: Early Detection and Intervention

The goal at this stage is to identify individuals exhibiting early symptoms in order to limit the effects and prevent the progression of the disease:

5.2.1 Toxicological Screening and Biological Monitoring

Regular testing for individuals working with pesticides, including measurements of blood cholinesterase levels and liver and kidney functions [2, 54, 55].

5.2.2 Poisoning Surveillance Systems

Public health institutions should actively utilize pesticide poisoning reporting and recording systems, and early identification of high-risk areas should be implemented [27, 56]. Turkey lacks adequate monitoring and registration systems for pesticides. Comprehensive studies and effective systems are needed in these areas.

5.2.3 Community-Based Screening

Neurological, endocrine, and psychological health screenings should be conducted for populations residing in areas with intensive pesticide use [57, 58].

5.3. Tertiary Prevention: Damage Reduction and Rehabilitation

The objective at this level is to prevent permanent damage and enhance the quality of life in individuals who have suffered health damage due to pesticide exposure:

5.3.1 Treatment in Centers with Toxicology and Neurology Specialization

Patients who have been poisoned should undergo appropriate rehabilitation and multidisciplinary follow-up.

5.3.2 Psychosocial Support

Psychological support should be provided for conditions such as depression, anxiety, or cognitive disorders that may develop following pesticide exposure. Additionally, given that a significant portion of acute pesticide poisonings is suspected to be related to suicide attempts, the importance of psychosocial support becomes even more evident.

5.3.3 Discontinuation of Exposure for Poisoned Workers

Workers who have developed chronic health issues due to pesticide exposure should be reassigned to alternative roles and provided with social security support [26, 59, 60].

6. Conclusion

To ensure effective control over pesticide use, licensing and regulatory inspection processes should be enhanced through greater transparency and stricter enforcement. Additionally, comprehensive education and awareness programs must be implemented at both the producer and consumer levels to foster informed decision-making and promote safer agricultural practices. Strengthening adherence to international agreements is crucial for the complete elimination of banned pesticides. In addition, offering financial and technical assistance for sustainable agricultural practices, including organic farming, is crucial for decreasing reliance on hazardous chemical inputs.

Addressing the challenges posed by pesticide use requires solutions that are not limited to individual actions but are instead grounded in systematic, science-based, and sustainable approaches. Such strategies are essential to ensuring the long-term viability of agricultural production while simultaneously protecting public health.

Ethical statements

The author confirms that no ethics committee approval or special authorization was necessary for this document.

Conflict of Interest

The author confirms that no conflicts of interest exist.

Authors' contributions

Both authors contributed to the preparation of this review article and read the final version.

Generative AI statement

The authors declare that no Gen AI was used in the creation of this manuscript.

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