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Pesticides and human health: a double-edged sword in modern agriculture

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Abstract

Without pesticides, global crop yields could decline significantly, as pests, fungi, and weeds threaten food production. Farmers rely on pesticides to prevent large-scale crop losses, ensuring food security and stable prices. While biopesticides have gained attention in recent years, chemical pesticides remain the primary defence against agricultural pests and diseases, playing a crucial role in sustaining global food supplies. Although many harmful pesticides have been restricted and modern formulations are considered safer for non-target species, extensive research indicates that pesticide residues can still pose long-term health risks to humans, animals, and ecosystems. Numerous research has associated pesticide exposure with increased rates of chronic diseases, including various cancers, diabetes, neurodegenerative disorders such as Parkinson's and Alzheimer's, birth defects and reproductive issues. This review explores the classification, mechanisms, benefits, and negative impacts of pesticides on human health and the environment, along with some strategies to mitigate their toxicity. Future research should prioritize innovative farming practices that reduce chemical pesticide use.

Keywords: Crop Protection, chronic disease, non-target organisms, pesticides, toxicity.

Introduction

With the increase in human population, there is a rising demand for food, making efficient agricultural production essential. Food crops are in competition with different weed species, worms and plant-eating insects. Thus, farmers turn to other ways and means to safeguard their crops. The most common thing farmers use to safeguard their crops is agricultural chemicals – pesticides and fertilizers. It is estimated that without pesticides, more than half of the world's crops could be lost to insects, diseases and weeds. Annually, 26% to 40% of potential crop yields are lost as a result of these factors.Without preventive measures, these losses could potentially double (Pesticide Facts 2017), resulting in a significant increase in global food prices.Pesticides enable farmers to grow more food on less land, thus increasing productivity per hectare. By mitigating pests and diseases, pesticides also minimize exposure to food polluted with harmful microorganisms and naturally occurring toxins, helping prevent food-related illnesses (USEPA2013).

According to USEPA (2014), pesticide is any substance or mixture designed to prevent, eliminate, repel, or control pests. Pesticides include insecticides, herbicides, fungicides, rodenticides, and plant growth regulators used to manage pests, diseases, and unwanted species in agriculture (**Fig. 1**). They help preserve agricultural products, ensuring safe storage and transportation, while reducing the risk of contamination. Additionally, they regulate plant growth, enhance yield and safeguard farm products from deterioration, contributing to food security.

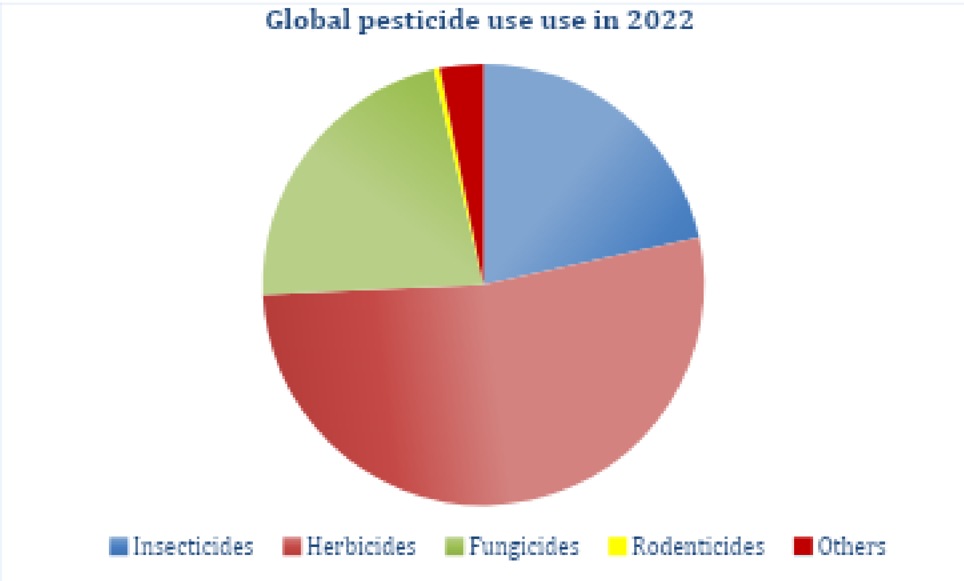

Fig. 1. Global pesticide use in 2022 according to different categories.
(**Source**: Pesticides use and trade. 1990–2022 by the Food and Agriculture Organization of the United Nations.)

The practice of using pesticides contributes to various environmental issues and poses significant risks to the well-being of both humans and animals. Over 98% of sprayed insecticides and 95% of herbicides disperse beyond their intended targets, affecting non-target species, air, water and soil (Saravi and Shokrzadeh 2011). The Green Revolution has significantly amplified global pesticide consumption over the past few decades. By 2022, worldwide agricultural pesticide usage had risen steadily, reaching 3.69 million metric tons. The leading countries in agricultural consumption of pesticides are listed in **Table 1**. In India, pesticide usage remains significantly high, with approximately 55,236 tonnes consumed during 2023–24. Uttar Pradesh, Maharashtra, Punjab, Telangana and West Bengal emerged as the leading consumers, collectively driving the pesticide demand (**Fig. 2**). Pesticides contribute to water pollution and soil contamination, with some classified as persistent organic pollutants. These chemicals are non-biodegradable, accumulating within the environment and entering the human food chain through contaminated food, water, and air. Despite regulatory controls, they persist in ecosystems, often detected in measurable amounts, including in marine life. Their long-term presence poses environmental and health risks, making pesticide exposure a significant concern (Kaur *et al*. 2019).

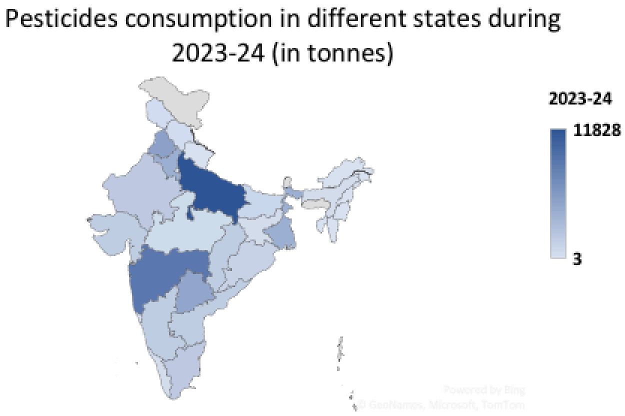

Fig. 2. Pesticides consumption in different states of India during 2023-24 (in tonnes) {**Source**: State-wise Consumption of Pesticides (Technical Grade) in India (2023-2024) by Indiastat.}

Pesticides extend beyond agriculture to significantly enhance public health by controlling vector-borne diseases (**Table 2**). They help reduce waterborne and insect-transmitted diseases such as malaria, Lyme disease and West Nile virus, preventing disease outbreaks by controlling rodent and insect populations. Pesticide application has greatly decreased the spread of diseases to humans, preventing an estimated seven million deaths since 1945 (Himeidan*et al*. 2012). The use of insecticides, a primary tool in vector control, has been pivotal in malaria control programs, leading to substantial declines in disease incidence. The use of pesticides in vector control is not limited to malaria; they are also used to combat vectors responsible for dengue, leishmaniasis, and Chagas disease (van den Berg *et al*. 2012). The strategic use of these chemicals has contributed to the decrease in morbidity and mortality associated with these illnesses.

Table 1. Leading countries in agricultural consumption of pesticides worldwide from 2018-2022 (in tonnes).

	Year				
Country	**2018**	**2019**	**2020**	**2021**	**2022**
Argentina	172928	204559	241294.2	241520	262506.9
Brazil	549280	620538	685746	719507	800652.2
Canada	87632	78893	92960	97692	97692
China	294682.5	273569.5	258757.9	244869.5	235760.4
Colombia	37773	69862	36711	39324	78230.75
France	83983.13	54303.71	64789.22	69697.52	67874.94
India	40093.69	40093.69	40093.69	40093.69	40093.69
Indonesia	261305.8	274421	213036.3	283297.1	294670.4
Russian Federation	74671.56	77306.76	90534.96	97018.45	97018.45
USA	457385.4	495672.7	474707.5	433770.9	467676.6
Vietnam	139416	134741.8	89334.84	148668.7	161908.1

(**Source**: Pesticides use and trade. 1990–2022 by the Food and Agriculture Organization of the United Nations.)

Table 2. Reported annual insecticide use in vector control operations in 2010–2019, by region and insecticide class, expressed in metric tonnes of active ingredient.

WHO region	**OC**	**OP**	**C**	**PY**	**NN**
African	337	390	335	34	35
Americas	0	1104	287	76	0
Eastern Mediterranean	0	15	47	25	1
European	0	1	0	0	0
South-East Asia	2977	92	3	31	0
Western Pacific	0	23	6	29	0
All	3314	1625	677	194	36

(**Source**: Global insecticide use for vector-borne disease control by World Health Organization, 2021) (**Note:** C, carbamates; NN, neonicotinoids; OC, organochlorines; OP, organophosphates; PY, pyrethroids)

Widespread pesticide use increases human exposure, causing acute effects like skin irritation, dizziness, and nausea, while chronic exposure is linked to cancer, respiratory issues, and diabetes. Pesticides contaminate food, water, and air, affecting vulnerable groups. Persistent chemicals bioaccumulate, heightening risks. This review examines health effects, toxicity mechanisms, epidemiological findings, regulations, and alternatives to minimize human exposure.

Benefits of organophosphate pesticides (OPs)

The four major groups of pesticides are organochlorine, organophosphate, carbamate and pyrethroid insecticides (Kaur *et al*. 2019). Among these, OPs remain prevalent due to their effectiveness and affordability, despite concerns about their harmful effects on human health and the environment. Market trends in pesticide use are influenced by agricultural demand, regulatory changes and advancements in pesticide formulation aimed at reducing toxicity and environmental impact (Metatech Insights 2025). Following are some of the main reasons why farmers choose OPs over other pesticides:

1. **Effectiveness**: Organophosphates are highly effective in controlling insect populations quickly, making them a valuable tool in managing severe pest infestations in agricultural settings and residential areas (Metatech Insights 2025). They work by inhibiting acetylcholinesterase, an enzyme crucial for neurotransmission, leading to the paralysis and death of target insects (Iyer *et al*. 2015).
2. **Low persistence**: Unlike some other pesticides, such as organochlorines, organophosphates break down rapidly in the environment. This reduces the risk of long-term environmental pollution and accumulation in ecosystems (Awe *et al*. 2022). Abiotic degradation, including hydrolysis and photodegradation, occurs rapidly under favourable conditions, especially in aerobic soils and sunlit waters. Malathion degrades quickly, reducing its environmental persistence. Biotic degradation further accelerates organophosphate breakdown, with microorganisms metabolizing diazinon and chlorpyrifos into less toxic by-products, significantly reducing their persistence in freshwater systems (Bondarenko *et al.* 2004).

Economic benefit: Organophosphates play a significant role in maintaining crop yields and preventing economic losses due to pest damage. Their use is particularly important in crops like broccoli, oranges, almonds and alfalfa, where alternative pest control methods may be less effective (Zhang *et al*. 2012). Other reason why OPs are commonly used is also that they are very low cost (Metatech Insights 2025).

3. **Disease vector control**: Organophosphate pesticides are widely used for controlling disease vectors, particularly in public health sectors. These insecticides are effective against a variety of pests and vectors of diseases such as malaria, dengue, and leishmaniasis (van den Berg *et al*. 2012). In vector control, organophosphates are used for residual spraying, space spraying, and larviciding (van den Berg *et al.* 2012). They are especially prevalent in regions like South-East Asia, where they are used intensively for malaria control (Hassan *et al.*2021).
4. **Resistance management**: Organophosphates have a low likelihood of inducing resistance in target pests, making them a reliable long-term solution for pest management (Khan *et al*. 2020). Additionally, the use of multiple organophosphate compounds with different potencies, such as chlorpyrifos and omethoate, has been shown to help manage resistance. For example, in field studies on Halotydeus destructor mites, omethoate remained effective even when resistance to chlorpyrifos was observed. Combining OPs or rotating them with other classes of pesticides can also delay resistance development (Umina *et al*. 2023).

Toxic effects of OPs on humans

Pesticides enter humans directly and indirectly, primarily through food (Kalyabina*et al*. 2021). Crops grown on contaminated soil accumulate pesticides in edible and inedible parts, reaching levels that pose health risks to humans and animals. Pesticides can enter the human body through the skin, ingestion, ocular contact, and inhalation. The routes of exposure include ingestion, inhalation, and dermal absorption (Kaur *et al*. 2019). In humans and animals, pesticides can be stored in fatty tissue or they may be metabolized into more toxic substances (Ray and Shaju 2023). Distinct from other organisms, humans are exposed to pesticides in three main ways namely intentional (accidental/suicidal), occupational and non-occupational exposures (Sabarwal *et al*. 2018).

Acute toxicity

Acute toxicity describes the harmful effects that occur following a single exposure or multiple exposures to a substance within a short duration, usually less than 24 h. Pesticides, designed to kill pests, can also pose a risk to human health through acute exposure. The severity of the effects depends on factors like the pesticide type, the dose, the route of exposure (inhalation, ingestion, skin contact), and individual susceptibility (Sabarwal *et al*. 2018).

Clinical symptoms of acute pesticide poisoning range from mild to severe. Mild exposure may cause skin or eye irritation, headaches, dizziness, nausea and vomiting, though severe cases can result in respiratory distress, muscle weakness, convulsions, unconsciousness, or even death. Recently, reports highlighted 17 deaths in a village in Jammu and Kashmir, with OPs identified as the primary cause (Sharma 2025).

Acute exposure to pesticides is often observed in individuals involved in pesticide application, especially without proper protective equipment. Organophosphate and carbamate pesticides inhibit acetylcholinesterase, leading to excessive airway secretions and bronchoconstriction, worsening conditions like asthma and chronic obstructive pulmonary disease (COPD) (Mamane *et al*. 2015).

Cholinesterase inhibition by organophosphate and carbamate pesticides triggers a cholinergic crisis with excessive salivation, sweating, tremors, and respiratory failure. Children are particularly vulnerable to the acute toxicity of pesticides as a result of their smaller body size, developing organs, and behaviours like putting things in their mouths (Buralli *et al*. 2020). Agricultural workers and pesticide applicators are also more vulnerable because of occupational exposure.

Chronic effects

Respiratory disorders

Exposure to pesticides has been increasingly recognized as a significant contributor to respiratory disorders. Pesticide exposure has been increasingly linked to respiratory disorders, affecting both agricultural workers and the general population. Pesticides, particularly organophosphates, carbamates and pyrethroids, contain volatile compounds which, when inhaled, may cause acute and chronic respiratory effects.

Chronic exposure is associated with long-term lung function decline and increased susceptibility to respiratory diseases. Research has connected pesticide exposure to an elevated risk of asthma, bronchitis and COPD (Mamane *et al*. 2015). Epidemiological studies have established a correlation between pesticide exposure and heightened incidences of respiratory conditions including asthma, COPD and lung cancer (Tarmure *et al*. 2020). Prolonged pesticide inhalation can induce oxidative stress, inflammation, and airway remodelling, contributing to irreversible lung damage. Additionally, pesticide-induced oxidative stress may impair immune responses, making individuals more vulnerable to respiratory infections (Doust *et al*. 2014). Occupational exposure is a significant concern, particularly among agricultural workers. Studies revealed that individuals in these professions exhibit more frequent cases of respiratory symptoms, including chronic bronchitis and asthma, compared to non-exposed populations (Mamane *et al*. 2015). Moreover, environmental exposure affects vulnerable populations such as children. Research indicates that children residing in proximity to farms utilizing pesticides like elemental sulfur experience reduced lung function and increased asthma-related symptoms (Buralli *et al*. 2020). Epidemiological studies indicate a higher incidence of asthma and reduced lung function in agricultural workers exposed to pesticides. Additionally, non-occupational exposure through contaminated air, water, and food poses respiratory health risks to the general population (Sabarwal *et al*. 2018).

The underlying pathophysiological processes behind these associations are complex. Certain pesticides, notably organophosphates, possess anti-cholinesterase activity, leading to laryngeal and bronchial constriction and can worsen asthma episodes and other respiratory symptoms. Additionally, these chemicals may trigger oxidative stress, overwhelming cellular detoxification processes and contributing to respiratory pathology (Salameh *et al*. 2006).

Developmental defects

Direct or indirect exposure to pesticides by pregnant mothers, can pose significant health risks. Exposure to pesticides during critical periods of human development has shown a connection with an increased risk of birth defects and developmental toxicity (Rappazzo *et al*. 2016). Prenatal pesticide exposure during the first and second trimesters is linked with diminished cognitive performance in infants, while third-trimester exposure is linked to delayed expressive communication and impaired fine motor skills (Suwannakul *et al*. 2021).

Studies have shown connections between parental pesticide exposure and congenital anomalies, including neural tube defects. For instance, research suggests that prenatal exposure to certain pesticides may elevate the risk of neural tube defects and anencephaly (Felisbino *et al*. 2024).

A study by Bouchard *et al*. (2011) showed that prenatal OPs exposure during pregnancy has been linked to lower cognitive abilities in children at age 7, with a 7-point IQ deficit observed in the highest exposure group. The study suggested that the developing foetal nervous system is particularly susceptible to OPs due to critical neurodevelopmental processes, including synapse formation and myelination.

Furthermore, in this study, researchers found a linear relationship between prenatal contact with organophosphate pesticides and cognitive decline in children. This means that as exposure increases, cognitive abilities decrease gradually and consistently, rather than deteriorating only at high exposure levels. The absence of a threshold implies that there is no known safe level of OPs exposure during pregnancy. Even minimal exposure levels were correlated with reduced IQ scores in children (Bouchard *et al*. 2011).

Research indicates that OPs can cross the placental barrier, potentially disrupting foetal development and increasing the risk of neurodevelopmental disorders such as attention deficit hyperactivity disorder (ADHD) and cognitive impairments (Chen *et al*. 2021; Choi *et al*. 2021).

Many pesticides function as endocrine disruptors (Singare 2016), as such they can interfere with hormonal pathways essential for normal foetal development. The routes of exposure are diverse, encompassing occupational contact among agricultural workers, residential proximity to treated areas, and dietary intake of pesticide residues (Rani *et al*. 2021). Notably, pesticides have been detected in maternal serum, placenta, and umbilical cord (Felisbino *et al*. 2024), indicating foetal exposure during gestation. This prenatal exposure underscores the vulnerability of developing foetuses to environmental toxins.

Neurodegeneration

Emerging research indicates a notable correlation between pesticide exposure and the development of neurodegenerative diseases like amyotrophic lateral sclerosis (ALS), Parkinson’s and Alzheimer’s disease. These diseases, which progressively damage the nervous system, pose significant socio-economic challenges (Yu *et al*. 2021). Pesticides are recognized neurotoxins, and their exposure has been linked to various neurodegenerative disorders, including mild cognitive impairment and dementia (Yan *et al*. 2016). A notable study by researchers at UCLA Health and Harvard identified ten pesticides that disrupted neurons associated with Parkinson's disease, providing new insights into how environmental toxins contribute to this condition (Paul *et al*. 2023).

Epidemiological studies have further supported these findings. For instance, research has demonstrated that exposure to pesticides is associated with at least a 50% increased risk of developing neurodegenerative diseases (Gunnarsson and Bodin, 2019). In addition, a study examining lifelong cumulative exposure to pesticides identified a significant link between this exposure and neurodegenerative diseases in the elderly. Specifically, past occupational exposure to pesticides showed an association with reduced cognitive performance and an increased risk of developing Alzheimer's disease and Parkinson's disease among older adults (Baldi *et al.* 2003).

Also, Hernández *et al*. (2016) established a strong link between prenatal organophosphate exposure and neurodevelopmental disorders, including altered mental or psychomotor development, pervasive developmental disorder and ADHD in children. Neuropathy and other brain damage are among the few signs of the patients exposed to OPs for a long time (Figueiredo *et al*. 2018; Uwaifo and John-Ohimai 2020). Prolonged exposure results in seizures, damages the amygdala most severely, followed by other brain regions, including the hippocampus and cortex (Figueiredo *et al*. 2018).

The mechanisms by which pesticides may induce neurodegeneration include the inhibition of acetylcholinesterase, leading to the accumulation of acetylcholine and subsequent neuronal damage (Kalyabina *et al*. 2021). Additionally, certain pesticides can generate oxidative stress, resulting in neuronal injury (Yan *et al*. 2016). Epigenetic modifications have also been implicated, where pesticide exposure leads to changes in gene expression without altering the DNA sequence, potentially triggering neurodegenerative processes (Yu *et al*. 2021).

Cancer

Pesticide use has been associated with a higher risk of various cancers, raising concerns about their impact on public health. The relationship between pesticide exposure and cancer development has been a subject of extensive research. Epidemiological studies have identified associations between pesticide exposure and various cancers, including leukaemia, lymphoma, and cancers of the different organs like brain, breast and skin (Cavalier *et al*. 2023). It is crucial to highlight that while occupational exposure to pesticides, such as in agricultural settings, has been associated with a higher incidence of cancer risks, the evidence for cancer risk from low-level exposure in the general population is less conclusive. For instance, Cancer Research UK states that there is no strong evidence that exposure to pesticides at low levels causes cancer (Cancer Research UK 2019). A study evaluating the consequences of pesticide use on cancer development in the United States found positive associations between pesticide use and increased rates of non-Hodgkin's lymphoma, leukaemia, colon, bladder, pancreatic, and lung cancer. The study indicated that the cancer risk from pesticide usage is equivalent to tobacco smoking (Gerken *et al*. 2024). Specific pesticides like atrazine, boscalid, dimethomorph, Dicamba, Dimethenamid, Dinotefuran, Glyphosate, Imazethapyr, and metolachlor were identified as primary contributors in areas with a high incidence of malignancies and colon cancers. Dimethomorph is linked to high risks of non-Hodgkin lymphoma and leukaemia. Glyphosate, a common herbicide, has been classified as a probable carcinogen by the International Agency for Research on Cancer (Gerken *et al*. 2024). Commonly used pesticides like OPs are also related to cancer (Sabarwal *et al*. 2018).

A study compared women with breast cancer to healthy women among farm workers, revealing that medium malathion use was linked to a higher breast cancer risk, though not significantly different across all cases. It was also discovered that exposure to any organophosphate, particularly chlorpyrifos, was associated with an elevated risk of breast cancer, especially in postmenopausal women. Repeated exposure to malathion further increased this risk, while a one-time exposure did not have a similar impact (Yang *et al*. 2020).

Diabetes

Pesticide exposure has been increasingly linked to the development of diabetes, marking it as a significant public health concern. Emerging research indicates a notable correlation between pesticide exposure and a greater risk of developing diabetes, particularly type 2 diabetes mellitus (Tyagi *et al*. 2021). Organochlorine pesticides (OCPs) may induce endocrine disruption, potentially leading to the development of diabetes (Tyagi *et al*. 2021). Epidemiological studies have identified a positive correlation between exposure to various classes of pesticides—including insecticides, herbicides, fungicides, rodenticides, and molluscicides—and the prevalence of diabetes. Research conducted in Thailand found that exposure to specific pesticides like endosulfan, mevinphos, carbaryl/Sevin, and benlate significantly increased the risk of diabetes. These findings align with previous epidemiological and animal studies (Juntarawijit and Juntarawijit 2018).

Glyphosate exposure has also been connected with adverse outcomes, with many epidemiological studies linking pesticide exposure to obesity and type 2 diabetes (Li *et al*. 2023). Leso *et al.* (2017) identified a probable link between pesticides, particularly organochlorines and organophosphates, and Diabetes Mellitus. Furthermore, studies demonstrate that individuals with higher pesticide exposure levels, such as agricultural workers, exhibit a greater risk of developing type 2 diabetes, gestational diabetes, and obesity. Conversely, consuming organic foods, which typically contain lower pesticide residues, has been linked to a reduced risk of diabetes and obesity (Poulia *et al*. 2024).

The mechanisms through which pesticides cause abnormal glucose regulation (AGR) and diabetes is thought to be by inducing oxidative stress, inflammation, and insulin resistance, as evidenced by studies on organophosphates, neonicotinoids, and persistent organic pollutants (POPs) (Kim *et al*. 2022). Exposure to chlorpyrifos, diazinon, and organochlorine pesticides has been associated with an elevated risk of diabetes. A meta-analysis revealed a 2.30 times higher risk of developing type 2 diabetes linked to these pesticide exposures (Kim *et al*. 2022). Glyphosate (commonly known as Roundup) seems to influence the gut microbiome, which has been associated with diabetes (Walsh *et al*. 2023).

The underlying mechanisms by which pesticides may contribute to diabetes involve disruptions in metabolic processes. Certain pesticides can interfere with nuclear receptors that regulate lipid and carbohydrate metabolism, such as peroxisome proliferator-activated receptors (PPARs). Alterations in PPAR activity can lead to insulin resistance and impaired glucose homeostasis, both of which are key factors in the development of type 2 diabetes (Hernández-Valdez *et al*. 2023).

Mitigation strategies

Organophosphates are chemicals widely used as pesticides and to control vector borne diseases, but they pose significant risks to human health due to their ability to inhibit acetylcholinesterase, an enzyme critical for nervous system function. Mitigating their effects requires a multifaceted approach involving regulation, exposure reduction and medical interventions. Some of the methods to mitigate are as follows.

1.**Regulatory measures**: Regulatory agencies must enforce rigorous testing of OP compounds before approval, ensuring they do not cause severe neurotoxic effects, as seen with compounds evaluated using the hen test for delayed polyneuropathy (Ehrich and Jortner 2010). Limiting OP use in agriculture and household products can reduce exposure. For example, alternatives to OPs-based sheep dips should be promoted (Kozawa *et al*. 2009).

2.**Reducing Exposure**: Workers handling OPs should wear personal protective equipment (PPE), such as gloves and respiratory masks, to minimize skin absorption and inhalation. Training programs for farmers and pesticide applicators can teach safe handling techniques, reducing risks during activities like orchard spraying or sheep dipping. Monitoring OP residues in food and water supplies is essential to prevent chronic low-level exposure in the general population.

3. **Medical monitoring and treatment**: Regular health checks for workers exposed to OPs can identify early signs of toxicity. Biomarkers like acetylcholinesterase activity levels can be monitored to assess exposure (Ehrich and Jortner 2010). Acute OP poisoning should be treated promptly with antidotes like atropine and oximes, which counteract the inhibition of acetylcholinesterase (Iyer *et al*. 2015). Individuals with chronic effects from OP exposure may require neurological and psychological support, as long-term complications include peripheral neuropathy and neuropsychological abnormalities (Iyer *et al*. 2015). In case of suspected poisoning, immediate medical attention is crucial, along with decontamination measures like removing contaminated clothing and washing the affected skin.

4. **Research and Public Awareness**: Continued research into the mechanisms of OP toxicity and safer alternatives is critical. Public awareness campaigns can educate communities about the risks of OP exposure and safe practices. By combining regulatory oversight, preventive measures, medical intervention, and education, the adverse effects of OPs on humans can be significantly mitigated.

Conclusion

Pesticides play a key role in controlling harmful organisms, enhancing crop yields, improving quality, and preventing economic losses by reducing commodity deterioration. They also aid in disease control. However, their potential health risks have become a growing concern. Occupational exposure, particularly among farmers and agricultural workers, is especially worrying, as they frequently handle significant quantities of these chemicals.

The growing body of evidence suggests that pesticides are involved and linked to the different diseases mentioned above and this has driven scientists to investigate how pesticides contribute to chronic diseases. While much remains to be explored, several mechanisms and pathways have been identified. These mechanisms often interact rather than act independently and may even heighten risks in genetically susceptible individuals. Given the substantial research linking pesticide exposure to chronic illnesses, it is increasingly recognized as a significant risk factor. With chronic diseases being a major global health concern, it is imperative to adopt preventive strategies.

Although there are downsides, such as potential harm to the environment and the development of pesticide-resistant pests, pesticides remain vital for maintaining current levels of food production and preventing widespread malnutrition. Therefore, while pesticides remain a cornerstone in the fight against pests and vector-borne diseases, it is crucial to implement integrated pest management strategies. This includes reducing pesticide use,minimizing dependency, and identifying safer alternatives to mitigate health risks associated with agrochemicals. Such approaches combine chemical and non-chemical methods, ensuring the sustainable and effective control of both agricultural pest and disease vectors.

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