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A comprehensive review of pesticide-induced environmental and biological hazards

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ABSTRACT

Pesticides, while being crucial for modern agriculture and food security, inflict significant harm on ecosystems, animal health, and humans. This comprehensive review synthesizes evidence of their multifaceted detrimental impacts. Environmentally, pesticides cause widespread contamination of soil, water, and air, leading to biodiversity loss, disruption of ecological balance (e.g., pollinator decline), and bioaccumulation within food chains. Animals, including livestock and wildlife, suffer from acute and chronic toxicity, reproductive failure, immunosuppression, and mortality due to exposure, with residues persisting in animal-derived foods. Human health is severely affected, with acute exposure causing poisoning and chronic exposure linked to neurodegenerative disorders (e.g., Parkinson's, Alzheimer's), various cancers (e.g., breast, prostate, and lymphoma), endocrine disruption, reproductive toxicity, and developmental defects. The persistence of certain chemical classes (e.g., organochlorines, organophosphates, and neonicotinoids) exacerbates these risks. Given the scale of the threat, the review underscores the urgent need for stricter regulations, enhanced residue monitoring, and a decisive shift towards sustainable alternatives like Integrated Pest Management (IPM) and organic farming to safeguard environmental integrity, animal welfare, and public health.

1. Introduction

Pesticides have played a significant role in modern agriculture by enhancing crop yields, controlling pests, and ensuring food security. However, their extensive and often indiscriminate use has raised serious concerns about their long-term consequences on the environment, animal welfare, and human health (Tang et al., 2023). These chemical agents, which include insecticides, herbicides, fungicides, and rodenticides, are designed to kill or deter living organisms,

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but their impact frequently extends beyond target species (Ahmad et al., 2024). With the intensification of agricultural practices, the reliance on synthetic pesticides has escalated, leading to widespread contamination of soil, water, and air. This contamination disrupts ecological balance, harms non-target organisms, and can result in the bioaccumulation and biomagnification of toxic residues within the food chain (Babaniyi et al., 2025).

Environmental degradation resulting from pesticide use is a growing global issue. Runoff from agricultural fields leads to contamination of surface and groundwater, affecting aquatic ecosystems and drinking water quality (Albou et al., 2024). Pesticide residues alter the microbial composition and fertility of soils, reduce biodiversity, and interfere with natural pest control mechanisms. Pollinators, especially honeybees, have been significantly impacted by neonicotinoid and other systemic pesticides, leading to colony collapse disorder and threatening global pollination services (Leska et al., 2021). Pesticides also have been implicated in the decline of bird populations, amphibians, and beneficial insects, disrupting entire ecological networks and threatening the sustainability of natural habitats (Yarkwan et al., 2024).

The implications for animal health are also profound. Livestock exposed to pesticide-contaminated feed or water may suffer from a range of subclinical and clinical effects, including reproductive failure, immunosuppression, and organ toxicity. Wildlife, particularly those in agricultural landscapes, are at high risk of chronic pesticide exposure (Liem et al., 2023). Birds of prey, aquatic species, and small mammals often accumulate pesticide residues, which can lead to altered behavior, impaired growth, and increased mortality. These impacts not only affect individual species but also destabilize ecosystems and disrupt predator-prey relationships (Grace et al., 2024).

In terms of human health, both acute and chronic pesticide exposures have been linked to a wide spectrum of health issues (Garud et al., 2024). Agricultural workers and individuals living in proximity to treated fields are especially vulnerable. Acute exposure may result in symptoms ranging from skin and eye irritation to respiratory distress and neurological dysfunction (Shweta et al., 2024). Chronic exposure, even at low doses, has been associated with endocrine disruption, developmental defects, reproductive disorders, neurodegenerative diseases, and various types of cancer. Children, pregnant women, and the elderly are particularly susceptible due to physiological sensitivities and prolonged exposure windows (Gachowska et al., 2024). Given the multifaceted and far-reaching consequences of pesticide use, there is a pressing need for comprehensive risk assessments, stricter regulatory frameworks, and the promotion of sustainable alternatives such as integrated pest management (IPM), organic farming, and biopesticides (Zhou et al., 2024). This review aims to explore the harmful effects of pesticides on the environment, animals, and human health by consolidating existing scientific literature and highlighting the necessity of adopting safer and more sustainable agricultural practices. By understanding these impacts, stakeholders including policymakers, researchers, and farmers can work towards mitigating the negative outcomes associated with pesticide dependency and safeguarding both ecological integrity and public health.

2. Materials and methods

For this comprehensive review, relevant literature was gathered from multiple academic and scientific databases, including Science Direct, Scopus, PubMed, ResearchGate, Google Scholar and National Centre for Biotechnology Information (NCBI). The search was conducted using a range of keywords such as pesticides, pesticide classification, effects of pesticides on human health, health hazards of pesticides, environmental impact of pesticides, pesticide regulation, legislation, and safety measures related to pesticide use.

3. Results and discussion

3.1. Pesticides effects on human health

Pesticides, though vital in modern agriculture for pest control and crop protection, pose significant risks to human health, especially when exposure is prolonged, unregulated, or occur at high levels. These chemicals can enter the human body through inhalation, ingestion, or skin contact, affecting various physiological systems depending on the nature, dose, and duration of exposure (Garud et al., 2024).

3.1.1. Acute health effects

Short-term or high-level exposure to pesticides can lead to acute poisoning, especially among agricultural workers or individuals handling chemicals without proper protective equipment. Common symptoms include headaches, dizziness, nausea, vomiting, skin and eye irritation, respiratory distress, muscle twitching, and in severe cases, convulsions or even death (Zardosht et al., 2024). Organophosphates and carbamates, for instance, are known to cause neurological symptoms by inhibiting cholinesterase activity (Voros et al., 2024).

3.1.2. Chronic health effects

Long-term exposure, even to low doses, has been associated with serious chronic health conditions. These include:

3.1.2.1. Neurological disorders

Prolonged exposure may contribute to the development of neurodegenerative diseases such as Parkinson's disease, Alzheimer's, and cognitive impairments. Alzheimer's disease (AD), the most common form of dementia, has been increasingly linked to long-term pesticide exposure, particularly organochlorines and organophosphates (Yadav et al., 2024). Studies, including case-control and meta-analyses, show a direct association between pesticide exposure and increased AD risk, especially in agricultural communities. Men are more frequently exposed due to occupational roles. Elevated dichlorodiphenyldichloroethylene (DDE) levels and prenatal pesticide exposure have been associated with cognitive impairments and developmental disorders in children (Botnaru et al., 2025). Neurological damage from pesticides affects memory and sensory functions by targeting basal forebrain cholinergic neurons. Historical incidents like the Gulf War and Tokyo sarin attack further highlight the long-term neurological impact of organophosphate exposure (Dubey et al., 2024).

Parkinson's disease (PD), the second most common neurodegenerative disorder after Alzheimer's, has been strongly linked to prolonged pesticide exposure. Pesticides like rotenone, paraquat, and mancozeb disrupt mitochondrial function, increase oxidative stress, and trigger neuronal apoptosis, particularly affecting dopamine-producing neurons. Animal studies confirm that rotenone causes neurodegeneration and motor dysfunction (Cao et al., 2019). Epidemiological studies, including cohort and case-control designs, consistently associate paraquat exposure with a higher risk of PD, with some showing up to a 25% increased risk (Ba et al., 2025). Paraquat induces reactive oxygen and nitrogen species, contributing to dopaminergic neuron loss in the substantia nigra. Meta-analyses confirm the link, especially with long-term or co-exposure to other chemicals like dithiocarbamates (Peng et al., 2005). Occupational exposure to pesticides and heavy metals is associated with earlier onset and increased mortality from PD. Duration of exposure plays a critical role in the severity of neurotoxic effects (Atterling et al., 2025).

Organophosphate and carbamate pesticides inhibit acetylcholinesterase, causing acetylcholine buildup and overstimulation of nerves, leading to symptoms like excessive salivation (Patel et al., 2024). Organochlorines such as endosulfan affect GABA receptors, disrupting inhibitory signaling and causing seizures, DNA damage, and neuronal hyperexcitability (Rodríguez et al., 2022). Some, like dicofol and indane, also impair sensory, motor, and cognitive functions. Pesticides such as pyrethroids and organophosphates generate oxidative stress by producing reactive oxygen species (ROS) and disrupting antioxidant defenses (Soliman et al., 2024). This oxidative damage harms neurons and contributes to neurodegenerative disease progression. Certain compounds also influence hormone levels, potentially leading to anxiety and behavioral disorders (Sharma et al., 2024).

3.1.2.2. Carcinogenic effects

Certain pesticides like glyphosate, DDT, and lindane have been classified as probable or possible human carcinogens. Chronic exposure may increase the risk of cancers including non-Hodgkin lymphoma, leukemia, and prostate cancer (Munoz et al., 2025).

3.1.2.3. Breast cancer

Scientific evidence increasingly links pesticide exposure to a higher risk of breast cancer, primarily through endocrine disruption and DNA damage. Many pesticides, including organochlorines like DDT and chlordane, exhibit estrogenic effects on mammary cells, promoting malignancy (Ugalde et al., 2024). Chlorpyrifos has been shown to cause oxidative stress and disrupt antioxidant defenses in breast cancer cells (Montanarí et al., 2024). Higher serum levels of DDE, a DDT metabolite, have been associated with increased breast cancer risk, particularly in women's exposed before age 14. Studies from regions like California and Tunisia confirm correlations between blood pesticide levels and breast cancer incidence. These findings highlight the carcinogenic potential of persistent agricultural chemicals (Bernhardt and House, 2025).

3.1.2.4. Bladder and colon cancer

Heterocyclic aromatic amines have been linked to colon and bladder cancers, with cancer risk increasing based on exposure level and duration. Imidazolinone herbicides, such as imazaquin and imazethapyr, have been implicated in bladder cancer through a large U.S. cohort study of over 57,000 pesticide applicators. These findings suggest occupational exposure to such herbicides may elevate cancer risk (Lucchesi et al., 2023). A case-control study in Egypt involving male agricultural workers also showed a significant association between pesticide exposure and bladder cancer, with an odds ratio of 1.68. These studies underscore the carcinogenic potential of long-term pesticide exposure in agricultural settings (Amr et al., 2015).

3.1.2.5. Brain cancer

The exact mechanisms by which pesticides contribute to brain tumors remain unclear, some exhibit genotoxic and hormone-disrupting effects that may promote cancer development. Research suggests that preconception and prenatal pesticide exposure are linked to a higher risk of infant brain tumors (Sokan-Adeaga et al., 2023). Residential exposure, particularly indoors, has been associated with gliomas in children. Parental occupational pesticide exposure further supports this link. Studies have also explored associations between pesticide exposure and adult brain tumors such as meningioma. However, current evidence remains limited and inconsistent, warranting further investigation (Gatto et al., 2021).

3.1.2.6. Liver cancer

Prolonged exposure to certain pesticides, especially classified carcinogens, has been associated with an increased risk of liver cancer. Some pesticides, like atrazine, chlorpyrifos and cypermethrin, possess genotoxic properties that can damage DNA and potentially lead to liver cell malignancies (Alavanja et al., 2004). Mechanisms such as oxidative stress, inflammation, and hormonal disruption are suspected to contribute to this risk. Organochlorine pesticides, in particular, have shown links to liver cancer due to their tendency to accumulate in the body over time. Occupational exposure among agricultural workers, especially pesticide applicators, is a key concern. However, more research is needed to establish a definitive causal relationship (Bassil et al., 2007).

3.1.2.7. Endocrine disruption

Pesticides are increasingly recognized for their potential to act as endocrine-disrupting chemicals (EDCs), interfering with the normal functioning of the endocrine system in both humans and animals. The endocrine system regulates vital biological processes through hormone signaling, including growth, development, metabolism, and reproduction. Certain pesticides mimic or block natural hormones, altering hormonal balance and leading to a range of health issues (Diamanti-Kandarakis et al., 2009). Many pesticides, particularly organochlorines (e.g., DDT, endosulfan), organophosphates, carbamates, and pyrethroids, have been shown to interfere with estrogenic, androgenic, thyroid, and other hormone pathways (Mnif et al., 2011). These chemicals can bind to hormone receptors, inhibit or stimulate hormone synthesis, and alter hormone metabolism. Such disruptions can result in reproductive abnormalities, infertility, developmental disorders, immune dysfunction, and metabolic diseases. In females, endocrine-disrupting pesticides have been linked to early puberty, menstrual irregularities, polycystic ovarian syndrome (PCOS), and even hormone-sensitive cancers such as breast and ovarian cancer (Gore et al., 2015). In males, exposure has been associated with reduced sperm quality, testosterone imbalance, testicular dysgenesis, and erectile dysfunction (Schug et al., 2011). Pesticides may also affect thyroid hormone function, which is critical for fetal brain development and metabolism regulation. Disruption of thyroid signaling can lead to cognitive deficits, developmental delays, and metabolic disorders. Prenatal and early life exposures are especially concerning, as they may result in permanent alterations to endocrine function and increase the risk of chronic diseases later in life (Zoeller et al., 2012).

3.1.2.8. Reproductive and developmental toxicity

Pregnant women exposed to pesticides may face increased risks of miscarriage, birth defects, low birth weight, and developmental delays in children (Sanborn et al., 2007). Fertility involves both male and female reproductive health, including sperm quality and the ability to conceive within a year (Wigle et al., 2008). While some studies found no association between pesticide exposure and sperm abnormalities, others reported links to sperm sex aneuploidies and erectile dysfunction (Martini et al., 2004; Perry et al., 2016). Women exposed to herbicides prior to conception showed increased infertility risk (Curtis et al., 1999). Research also indicates that dietary exposure to pesticides, particularly through fruits and vegetables, may affect male fertility. Men consuming produce with high pesticide residues had lower sperm count, volume, and normal morphology (Chiu et al., 2015). Even low-to-moderate pesticide intake influenced sperm quality, suggesting that both occupational and dietary pesticide exposure can negatively impact human reproductive health (Mínguez-Alarcón et al., 2019).

Neural tube defects (NTDs) are among the most severe congenital disorders, and studies suggest a strong link with prenatal exposure to organochlorine pesticides (OCPs). In northern China, a case-control study using umbilical cord tissue found higher levels of OCPs in NTD-affected pregnancies. GC-MS analysis revealed significant associations between 16 OCPs and increased NTD risk (Zhao et al., 2014). Additionally, international studies from nine countries consistently link pesticide exposure to various birth defects, including urogenital, limb, orofacial, and ocular anomalies (Cavieres et al., 2002; Garcia et al., 1999). Parental pesticide exposure, especially during pregnancy, was also associated with a heightened risk of congenital abnormalities (Rocheleau et al., 2015). These findings highlight the reproductive hazards of pesticide exposure. Pesticide exposure has been associated with adverse pregnancy outcomes such as natural abortion, stillbirth, fetal, and neonatal death. Across various studies, 9 out of 11 showed a positive correlation between pesticide exposure and these outcomes (Wigle et al., 2008). The Ontario Farm Study indicated that preconception exposure is linked to early miscarriages, while postconception exposure relates to later losses (Arbuckle et al., 2001). In the Philippines, farming families using high pesticide levels had a sixfold higher risk of spontaneous abortion than those practicing integrated pest management**.** These findings emphasize the reproductive risks of pesticide exposure during critical pregnancy periods (Garry et al., 2002).

3.1.2.9. Immunotoxicity

Pesticides may weaken the immune system, making individuals more susceptible to infections and diseases (Sanborn et al., 2007; Corsini et al., 2013). Pesticides have been shown to exert immunotoxic effects, impairing both innate and adaptive immune responses (Thrasher and Kilburn, 2001). Exposure to certain pesticides, such as organophosphates, carbamates, organochlorines, and pyrethroids, can weaken immune function by disrupting immune cell signaling, reducing antibody production, and altering cytokine levels (Galloway and Handy, 2003). This immunosuppression increases susceptibility to infections, slows wound healing, and may reduce vaccine efficacy (Keil et al., 2009). Chronic exposure has also been linked to hypersensitivity reactions, autoimmune disorders, and chronic inflammatory conditions (Selgrade, 2007). Children and agricultural workers are particularly vulnerable due to higher exposure levels and weaker immune resilience (Repetto and Baliga, 1997). Some pesticides may even trigger immune over activation, contributing to allergic reactions or asthma (Colosio et al., 2013).

3.2. Pesticides impact on environmental sustainability

Pesticides, while crucial for crop protection, pose serious environmental risks due to their persistence and mobility through air, water, and soil (Carvalho, 2017; Sanborn et al., 2007). Runoff, leaching, and spray drift lead to widespread contamination, affecting soil health, aquatic ecosystems, and biodiversity (Aktar et al., 2009). Persistent residues disrupt soil fertility by harming beneficial organisms like earthworms and microbes (Goulson, 2013). In Europe, 83% of topsoil samples were found to contain pesticide residues (Silva et al., 2019), and aquatic environments often suffer from oxygen depletion, fish mortality, and reproductive harm due to herbicide contamination (Stehle and Schulz, 2015). Indian studies have also reported high levels of pesticides in drinking water and aquatic organisms, raising concerns about ecosystem and public health (Sharma et al., 2019). Pesticides accumulate in the food chain, threatening non-target species such as birds and mammals by reducing fertility and immunity (Mineau and Whiteside, 2013). Contamination affects all trophic levels, causing bioamplification and ecosystem imbalance (Walker et al., 2012). Soil and root interactions are disrupted, inhibiting essential biological processes and nutrient cycling (Tilman et al., 2002). Moreover, prolonged use leads to pesticide resistance in pests, increasing reliance on more toxic chemicals and worsening environmental impacts (Pretty and Bharucha, 2015). These findings highlight the urgent need for sustainable pesticide management practices.

3.3. Pesticides impact on animal health

Pesticides, while beneficial for controlling pests in agriculture, pose significant risks to animal health across a wide range of species (Sanborn et al., 2025). Exposure can occur directly through ingestion, inhalation, or dermal contact, and indirectly via contaminated food, water, or the environment (Panseri et al., 2020). These chemicals cause both acute and chronic toxicity in domestic, wild, and aquatic animals (Reeves et al., 2021). In livestock and poultry, pesticide exposure has been associated with reduced feed intake, reproductive dysfunction, endocrine disruption, hepatic and renal toxicity, and immunosuppression (Tripathi et al., 2022). Residues present in animal feed or water can bioaccumulate in tissues, thereby compromising the safety and quality of animal-derived products such as meat, milk, and eggs, and posing indirect risks to human health (Islam et al., 2024). Wildlife species are especially vulnerable. Birds may ingest pesticide-contaminated insects or seeds, leading to eggshell thinning, behavioral alterations, and population declines (Hallmann et al., 2023). Apex predators suffer from biomagnification, where pesticide concentrations increase at higher trophic levels, impairing reproduction and immune competence (Boone et al., 2020). Aquatic animals like fish and amphibians are highly sensitive to pesticide-laden runoff. Insecticides and herbicides can impair gill function, damage reproductive tissues, and induce deformities and mortality (Silva et al., 2021). Herbicide-induced destruction of aquatic vegetation further depletes dissolved oxygen, causing fish kills and disrupting aquatic ecosystem dynamics (Schulz et al., 2023). Even companion animals are not spared. Dogs and cats may experience neurological symptoms, vomiting, dermatitis, and seizures after exposure to insecticides such as organophosphates and pyrethroids used in household and garden applications (Gong et al., 2022). Overall, pesticides significantly compromise animal health, contributing to illness, reduced productivity, and increased mortality.

3.4. Pesticide residues in food of animal origin

Pesticide residues in food of animal origin have become a significant public health concern due to the bioaccumulation and persistence of these chemicals in the food chain (Sanborn et al., 2025). Animals exposed to pesticides either directly through contaminated feed and water or indirectly through the environment can accumulate residues in their tissues, milk, eggs, and other products (Pathak et al., 2021). These residues pose potential risks to human health when such animal-derived foods are consumed. Lipophilic pesticides, particularly organochlorines like DDT, aldrin, dieldrin, and endosulfan, are known for their ability to persist in fat tissues of animals. Even after bans or restrictions, their residues can still be detected due to their long environmental half-lives (Kumar et al., 2023). Organophosphates, pyrethroids, and carbamates may also be found in lower concentrations in animal products, although they tend to degrade faster (Ali et al., 2022).

Milk is one of the most commonly contaminated animal products due to its high fat content, providing a medium for fat-soluble pesticide accumulation. Studies have shown pesticide residues such as DDT, lindane, and endosulfan in cow and buffalo milk, sometimes exceeding permissible limits (Dixit et al., 2020). Meat and fat tissues can retain pesticide residues when animals graze on contaminated pastures or are fed treated feed. Similarly, eggs and fish from contaminated waters have been reported to contain detectable levels of pesticides, impacting food safety (Verma et al., 2024).

Chronic exposure to pesticide residues through animal-derived foods can lead to health issues such as endocrine disruption, carcinogenicity, reproductive toxicity, and neurotoxicity (Singh et al., 2023). Infants and young children are particularly at risk due to their developing systems and higher consumption relative to body weight. To mitigate these risks, regular monitoring, stringent regulation of pesticide use in agriculture and veterinary practices, proper withdrawal periods before slaughter or milking, and public awareness are essential (Sharma and Das, 2022). Promoting organic and integrated pest management (IPM) practices also helps reduce the presence of pesticide residues in food of animal origin.

3.5. Approaches for safety measures against pesticide hazards

To reduce the harmful impact of pesticides on human health, animals, and the environment, several safety approaches and preventive strategies can be implemented. These include regulatory, technological, agricultural, and educational measures:

3.5.1. Strict regulatory control

Strict regulatory control plays a vital role in minimizing the risks associated with pesticide use. One essential measure is the enforcement of Maximum Residue Limits (MRLs) in food and animal products, ensuring that pesticide levels remain within safe boundaries for human consumption (Sanborn et al., 2025). Regulatory authorities should also ban or restrict the use of highly hazardous and persistent pesticides, particularly those known for bioaccumulation and long-term environmental persistence, such as certain organochlorines (Ganesan et al., 2023). Additionally, the approval and registration of pesticides must be continuously reviewed and updated based on the latest scientific evidence, including toxicological data and environmental impact assessments, to ensure ongoing safety and compliance (Alam et al., 2021). These regulatory actions are crucial in protecting public health, preserving biodiversity, and promoting sustainable agricultural practices (Rathi and Joshi, 2022).

3.5.2. Personal protective equipment (PPE)

The use of PPE is essential for reducing pesticide exposure among farmers and applicators. Wearing gloves, masks, goggles, and protective clothing helps prevent skin absorption, inhalation, and eye contact with harmful chemicals (Sanborn et al., 2025). It is equally important to promote safe practices during pesticide handling, mixing, and application. Proper training should be provided to ensure that individuals follow safety protocols, reducing the risk of acute poisoning, long-term health effects, and environmental contamination during pesticide use (Sarkar et al., 2021; Yadav et al., 2023).

3.5.3. Good agricultural practices (GAP)

Good agricultural practices are essential to ensure safe and responsible pesticide use. Farmers should strictly use only approved pesticides, applying them at recommended doses and at proper intervals to avoid overuse and environmental contamination (Sanborn et al., 2025). Adhering to pre-harvest intervals ensures that pesticide residues degrade to safe levels before the crop is harvested. Similarly, following withdrawal periods in livestock helps minimize pesticide residues in milk, meat, and eggs, protecting consumers from exposure through animal-derived food products (Tripathi et al., 2022; FAO, 2023).

3.5.4. Integrated pest management (IPM)

IPM emphasizes sustainable pest control by combining multiple strategies to minimize chemical pesticide use. It encourages adopting non-chemical methods such as introducing natural predators, practicing crop rotation, and cultivating pest-resistant crop varieties. These approaches help maintain ecological balance and reduce pest resistance. Chemical pesticides are used only when absolutely necessary and in a targeted, limited manner. This reduces environmental impact, safeguards beneficial organisms, and promotes long-term agricultural productivity and food safety (Sanborn et al., 2025).

3.5.5. Education and awareness

Education and awareness are critical components in promoting the safe use of pesticides. Farmers, veterinary workers, and pesticide handlers should receive proper training on pesticide handling, application techniques, storage, and disposal to minimize health and environmental risks (Gupta et al., 2022). Public awareness campaigns can highlight the dangers of pesticide exposure and the importance of residue-free food. Educating communities fosters responsible behavior, encourages the adoption of safer alternatives, and empowers individuals to make informed decisions that protect both human and environmental health (Sanborn et al., 2025).

3.5.6. Residue monitoring and surveillance

Residue monitoring and surveillance are essential for ensuring food safety and environmental protection. Regular screening of food products, soil, water, and animal tissues helps detect harmful pesticide residues and assess compliance with safety standards (Kumar et al., 2021). Establishing centralized laboratories equipped with advanced analytical tools such as Gas Chromatography-Mass Spectrometry (GC-MS) or Liquid Chromatography-Mass Spectrometry (LC-MS) enables precise and reliable detection. These efforts support regulatory enforcement, risk assessment, and timely action to prevent contaminated products from reaching consumers (Sanborn et al., 2025).

3.5.7. Proper storage and disposal

Proper storage and disposal of pesticides are crucial for preventing accidental exposure and environmental contamination. Pesticides should always be stored in their original, labeled containers and kept securely away from food, animal feed, and water sources to avoid cross-contamination. Expired or unused pesticides must never be discarded in open fields, drains, or water bodies. Instead, they should be disposed of through authorized collection programs or hazardous waste facilities. Similarly, empty containers must be triple-rinsed and properly discarded or recycled (FAO, 2023; Sanborn et al., 2025).

3.5.8. Promotion of organic farming

Promoting organic farming is a sustainable approach to reducing pesticide dependence and exposure. Governments and institutions should support chemical-free farming through financial subsidies, technical training, and access to organic inputs. Educating farmers on natural pest control methods and soil health management can enhance productivity without synthetic chemicals (Tripathi et al., 2024). Simultaneously, raising consumer awareness and encouraging the consumption of certified organic animal products can create market demand, driving more producers to adopt eco-friendly practices that ensure safer food and a healthier environment (Sanborn et al., 2025).

4. Conclusion

The extensive evidence presented in this review underscores the profound and multifaceted harm inflicted by pesticides on environmental integrity, animal health, and human well-being. Pesticide contamination permeates ecosystems, causing biodiversity loss, soil degradation, and aquatic toxicity, while bioaccumulation threatens wildlife and livestock through immunosuppression, reproductive failure, and mortality. Human exposure occupational or dietary is unequivocally linked to acute poisoning, chronic conditions (e.g., neurodegenerative diseases, cancers, endocrine disruption), and intergenerational health risks. Despite their agricultural utility, conventional pesticides jeopardize planetary sustainability and public health. Urgent adoption of stringent regulations, enhanced monitoring, and agroecological alternatives notably Integrated Pest Management (IPM) and organic farming is imperative to mitigate these risks. Prioritizing safer practices will safeguard ecological resilience, food safety, and global health for future generations.

Conflicts of interest and financial disclosures

The authors state that there are no conflicts of interest to disclose.

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