EVALUATING THE TOXIC EFFECTS OF PESTICIDES ON NON-TARGET ORGANISMS: A CURRENT REVIEW

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ABSTRACT
Recent studies have highlighted the harmful effects of pesticides on a wide range of organisms, including predatory insects, bees, fish, and humans, underscoring both ecological and health-related concerns. Predatory insects experience reduced hunting efficiency and reproductive success due to pesticide exposure, disrupting food chains and compromising ecosystem stability. Bees, essential pollinators in agriculture, suffer from impaired navigation and decreased reproduction, contributing to population declines and lower crop yields. In aquatic environments, pesticide exposure disrupts reproductive cycles and alters fish behavior, particularly affecting juvenile survival. The potential health risks for humans are also alarming, with long-term exposure linked to cancer, neurological disorders, and reproductive issues. The growing body of evidence highlights the urgent need for sustainable agricultural practices and a reduction in pesticide use. Advancing alternative pest management strategies and protecting biodiversity are essential to mitigate these harmful effects and maintain ecological balance. This review aims to consolidate recent research on the diverse impacts of pesticides across multiple species and explore their broader implications for ecosystem health and human well-being.
Keywords: Ecotoxicology, Non-Target Organisms, Pesticide Toxicity.

INTRODUCTION

Pesticides are chemical and biological compounds that are widely used to prevent yield loss in agricultural fields by controlling factors like fungi, bacteria, insects, rodents, and weeds (Van der Werf, 1996; Kumar et al., 2023; Bütüner & Susurluk, 2023; Yaraşır et al., 2024; Susurluk et al., 2024). Pesticides are categorized by target organisms, mechanisms of action, modes of effect on target organisms, and groups of active substances (Casida, 2009; Valbuena et al., 2021).

Herbicides are utilized for the control of weeds. Insecticides are designed to control harmful insects, with pyrethroids and neonicotinoids being notable examples within this category. Fungicides are employed to control fungal diseases that have an effect on plants. Rodenticides are used to control rodents. Biological pesticides are those derived from natural sources, often exhibiting lower toxicity. *Bacillus thuringiensis* (Bt) is a notable example of this group (Clarke

et al., 1997; Fedtke & Duke, 2004; Yadav & Devi, 2014; Ansari et al., 2014; Samarghandi et al., 2017).

Over the years, various pesticides have been employed to manage factors contributing to yield loss. Historical records show that ancient Egyptians and Mesopotamians used salt and sulfur for pest control (George, 1999; George et al., 2010). By the mid-19th century, the development of chemical pesticides accelerated. In 1867, Bordeaux mixture a combination of sulfur and copper sulfate marked the beginning of modern pesticide applications (Clark, 1902; Crandall et al., 1909; Millardet, 1933). By the mid-20th century, the widespread use of synthetic pesticides revolutionized agriculture. Organochlorine compounds such as DDT (dichlorodiphenyltrichloroethane) emerged as effective insecticides during that period (Dicker et al., 1946; Nasir, 1947). However, due to the environmental and health issues associated with DDT, its use was restricted in the 1970s (Mitjavila et al., 1981; Turusov et al., 2002; Beard, J., & Australian Rural Health Research Collaboration, 2006). Today, pesticide technology has advanced considerably, remaining a key tool for managing diseases and pests that threaten agricultural productivity.

However, recent scientific advancements have uncovered toxic effects of pesticides on non-target organisms (Tsaboula et al., 2016; Barathi et al., 2024). Research has highlighted both direct and indirect toxic impacts on beneficial insects, bees, fish, animals, and humans (Ansari et al., 2014; Cullen et al., 2019). Despite DDT being banned for decades, traces of it have been found in snow samples collected from the summit of Mount Everest (Wang et al., 2016; Nevitt & Percival, 2022; Sood et al., 2022). In response to such environmental concerns, the European Union introduced pesticide restrictions in 2009 as part of its chemical management strategy, encouraging the adoption of alternative methods for pest and disease control (Marchand & Robin, 2019; Dede et al., 2022; Susurluk & Bütüner, 2024a; Susurluk & Bütüner, 2024b). This study aims to review recent findings on the toxic effects of pesticides on non-target organisms, emphasizing the need for sustainable pest management practices.

TOXIC EFFECTS OF PESTICIDES ON PREDATOR (BENEFICIAL) INSECTS

Pesticides are widely utilized in agricultural production to manage pest populations. However, their effects on ecosystem dynamics are complex and multifaceted. In particular, predator insects play a critical role in maintaining ecosystem balance (Martinou et al., 2014; Gorri et al., 2015; Stanley et al., 2016; Serrão et al., 2022). The impact of pesticides on these predators can be observed through both direct and indirect pathways. Direct effects arise from the harm caused to non-target insects by these chemicals. Indirect effects are known to stem from the influence of pesticides on food chains and interactions within ecosystems. Pesticides can alter the dynamics of prey populations by affecting their predators (Sánchez-Bayo, 2021; Serrão et al., 2022; Mata et al., 2024). In a study by Knapp et al. (2024), the toxic effects of 22 pesticides were evaluated on predator snout mites (Trombidiformes: Bdellidae). The results demonstrated that some pesticides had toxic effects on these mites. Similarly, Kou et al. (2024) investigated the impact of cadmium on predator insects from the genus *Orius* (Hemiptera: Anthocoridae). Their research revealed that cadmium, which enters the soil through various sources, exerts toxic effects on *Orius* species, further highlighting the environmental risks posed by contaminants.

TOXIC EFFECTS OF PESTICIDES ON BEES

Pesticides affect bees through three primary pathways: ingestion, contact, and respiratory exposure. Bees are generally exposed to these chemicals while foraging in agricultural environments. In areas where pesticides are applied, they come into direct contact with treated plants. Additionally, contaminated water sources and surrounding vegetation can lead to

indirect exposure, causing toxic effects. Some pesticides are known to impair bee activity, induce paralysis, and often result in mortality (Özbek, 2010).
Buluş et al. (2024) demonstrated that neonicotinoid insecticides cause memory impairment in *Bombus terrestris* L. (Hym: Apidae). Similarly, Kita et al. (2024) found that pesticide exposure can reduce bee survival time by up to fivefold. Mueller et al. (2024) reported that pesticides used in apple orchards negatively impact all pollinators, with *Apis mellifera* L. (Hym: Apidae) being more severely affected than other species. Furthermore, Zhang et al. (2024) revealed that buprofezin, previously considered harmless to bees, is in fact toxic and significantly increases larval mortality.

TOXIC EFFECTS OF PESTICIDES ON FISHES

Pesticides carried into the soil by rain and irrigation water can contaminate groundwater, streams, reservoirs, and marine ecosystems, posing serious risks to organisms within these environments (Ghafarifarsani, 2024). These effects may result in direct mortality, reduced reproductive success, and tissue damage. In a study conducted in Pakistan, Ullah et al. (2024) found that pesticide exposure in fish triggered behavioral, hematological, histopathological, genotoxic, and endocrine disruptions.
Hartz et al. (2024) evaluated the toxicity of three pesticides on Chinook salmon and identified bifenthrin as the most acutely toxic. Similarly, Elayi and Williams (2024) studied the effects of cypermethrin on *Aplocheilus lineatus* (Cyprinodontiformes:Aplocheilidae), an insectivorous fish species, and reported significant behavioral changes following exposure. Souza et al. (2024) assessed the impact of four pesticides on *Colossoma macropomum* (Characiformes: Serrasalmidae), finding increased neurotoxicity linked to pesticide exposure. Additionally, Banaee et al. (2024) examined the effects of imidacloprid and chlorpyrifos on carp, revealing oxidative stress and disruptions in blood biochemistry in exposed individuals.

TOXIC EFFECTS OF PESTICIDES ON ANIMALS

The effects of pesticides on animals are generally categorized into two types: acute and chronic toxicity (Rizzati et al., 2016; Gupta & Gupta, 2022; AbuQamar et al., 2024). Acute toxicity refers to the immediate impact following pesticide exposure. Some pesticides, particularly organophosphates and carbamates, act as neurotoxins, impairing normal neural function. Exposure to these chemicals can cause symptoms such as tremors, seizures, and, in severe cases, death. Birds, mammals, and aquatic organisms are particularly vulnerable to acute exposure through direct contact, ingestion of contaminated food or water, or inhalation of pesticide particles (Berny, 2007; Hashimi et al., 2020; Ayilara et al., 2023; Bishop et al., 2024).
Chronic toxicity, in contrast, arises from prolonged exposure to low doses of pesticides, leading to long-term health issues. These may include reproductive and developmental problems, immunotoxicity, and heightened disease susceptibility (Ramsingh, 2010; Soares et al., 2016; Kaur et al., 2024). In a study by Miclean et al. (2024), pesticide residues were detected in cow's milk, likely originating from pesticides that had entered the soil and subsequently contaminated water and feed sources. Similarly, Rizzo et al. (2024) examined the effects of organophosphate poisoning in Lacaune sheep, including the risk of mortality, underscoring the importance of careful pesticide use, particularly in areas designated for livestock farming.

TOXIC EFFECTS OF PESTICIDES ON HUMANS

Pesticides enter the human body through multiple pathways and can cause a range of toxic effects. Asefa et al. (2024) found that pesticide exposure in Ethiopia is linked to acute

poisoning, respiratory disorders, neurological and behavioral issues, and breast cancer. In Türkiye, Aktaş et al. (2024) reported that the active ingredients pyridaphenthion, dinoseb, diazinon, and pirimiphos-methyl on peppers exceeded the maximum acceptable residue limits (MRL). Gautam et al. (2024) highlighted the harmful effects of pesticides on the male reproductive system, noting impacts on sperm morphology, testicular structure, and spermatogenesis, posing serious risks to reproductive health. In China, Hu et al. (2024) collected air samples from a residential area near agricultural fields and detected nine pesticides, with beta-cyhalothrin exceeding acceptable limits and acetochlor surpassing the cancer risk threshold (1E-6). Similarly, Singh et al. (2024) associated glyphosate exposure with an increased risk of cancer, kidney disease, attention deficit, hyperactivity, autism, Alzheimer's, and Parkinson's disease. Jasrotia et al. (2024) found that pesticide exposure contributes to cancer and birth defects. In India, Kumar and Sinha (2024) detected 28 different pesticides in blood and urine samples from agricultural workers. Additionally, Remigio et al. (2024) established a link between the active ingredient atrazine and cancer. Their research also revealed an increase in lung and prostate cancer cases among agricultural workers exposed to pesticides.

CONCLUSION

In agriculture, pesticides are widely used to control diseases, pests and weeds; however, their toxic effects on humans, animals, fish, bees and beneficial insects cannot be ignored. Studies show that pesticide exposure negatively impacts health, disrupts ecosystem balance, and accelerates biodiversity loss. In particular, the decline of bees and other pollinators presents a serious threat to the future of agriculture. To protect both environmental and human health, it is essential to transition toward more sustainable alternatives. Comprehensive research and policy reforms are needed to develop solutions that support agricultural productivity while preserving ecosystem integrity.

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