CHAPTER 12

Toxicological Stress In Fish By Pesticides

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DOI-
https://doi.org/10.59436/B978-81-971444-7-9/12

Pesticides are using all over the world for more than half a century to control crops from broadleaf and certain grassland weeds. Their continuous widespread use has made them a critical problem in the environment, especially in aquatic habitats. The continuous application of synthetic chemicals in modern agriculture has resulted in various environmental concerns, indirectly they affect the aquatic ecosystems when. Among these chemicals, insecticides, which are used to prevent crops from insects; fungicides, which are used to avoid damage from fungi; herbicides, which are commonly used to manage unwanted vegetation; rodenticides, which are used to kill rodents and other vertebrates, have become a focal point due to their widespread usage and persistence in the environment. Hošťovský *et al.*(2014) investigate that certain group of herbicides, insecticides, fungicides and rodenticides including trazine, Dichlorodiphenyl- trichloroethane (DDT), Phosphide, Difenacoum respectively, are among the most commonly used globally. They are highly effective in protecting crops, yet their persistent nature and ability to contaminate water bodies have raised significant environmental concerns. Their detrimental effects on non-target aquatic organisms, particularly fish, have been well reported in recent years. This is an alarming condition because the potential of fish to bioaccumulate in aquatic food chains, thereby affecting not only individual species but also entire aquatic ecosystems. One of the primary concerns regarding pesticide contamination is its impact on the health of aquatic organisms. Fish are often considered indicators for environmental pollution, as they can be exposed to pollutants in their habitat and serve as a link in the food chain. Fish exhibit various serious responses to toxic substances, including alterations in behavior, physiology, and biochemistry. The study of these responses is crucial in understanding the broader ecological implications of pesticide contamination. The changes in different organs can signal stress, immune suppression, or systemic damage, offering valuable insight into the sub-lethal effects of contaminants. Fish are ecologically significant and sensitive to environmental changes that make them an excellent subject for monitoring as an indicator of water quality. This chapter explain that these changes in certain fish species are particularly sensitive to environmental stressors, and as such, can serve as reliable biomarkers of exposure to toxicants like pesticides. This chapter focus on synthesizing existing research concerning on toxicological stress in fish by the impact of pesticides on the physiological functions and different organs of the freshwater fish. However, their persistence in aquatic environments and potential to bioaccumulate in aquatic organisms has raised significant concerns about their environmental impact. This chapter stated several studies investigating how exposure to triazine herbicides influences their key organs including gills, liver, muscles, kidney, nervous system, reproductive system, blood indices. By examining various experimental studies, the chapter would assess how these pollutants induce stress responses, immune suppression, and potential systemic damage in this species. The chapter would also highlight the significance of these hematological parameters as biomarkers for ecological monitoring and early warning systems in aquatic ecosystems affected by agricultural runoff and herbicide contamination.

Pesticides

According to the food and agriculture organization (FAO), A pesticide is any substance or mixture of substances intended for repelling, destroying or controlling any pest, including unwanted species of plants or animals causing harm during or otherwise interfering with the production, processing, storage, transport or marketing of food, agricultural commodities, wood and wood products or animal feedstuffs; it also includes substances used as plant-growth regulators, defoliants or desiccants.

Categories Of Pesticides

Rajak *et al.*,(2023) state that Several categories of pesticides have been manufactured that target different pests with various modes of action to minimize agriculture- based economic loss. Based on the target organism Pesticides can target several pests of different taxa and group of organisms. Based on the target organism, pesticides have been categorized as follows:

1. Insecticides

Several insect pests damage growing crops by chewing leaves and burrowing stems, fruits, or roots. These insects significantly reduce the overall production of agricultural stuffs around the globe. Chemical formulations used to eradicate or control the population of such insects are termed insecticides. Most pesticides used in India and other developing countries belong to this category. Acephate, Cryolite, Dichlorodiphenyl- trichloroethane (DDT), Chlorpyrifos, Malathion, Parathion, Aldrin etc., are common insecticides used for the purpose.

2. Fungicides

Plants come in contact with several fungi living in the soil. The outcomes of such contact may be mutualistic or parasitic (Bever *et al.,* 2012). Parasitic fungi impart direct or indirect damage to stored grains, crops, and vegetables. Fungal attacks can destroy plant tissues by producing potent toxins. They are also responsible for the spoilage of stored grains and food materials. Therefore, eradicating the fungal population from agricultural fields and storehouse is necessary to increase agricultural yield. Substances have been formulated to control fungal problems like molds, mildew, and rust. These substances are known as fungicides. Common fungicides include Phosphide, Methyl bromide, Ethylene di- bromide, Mefenoxam, Sulfur, and Mancozeb.

3. Herbicides

Herbs are small plants unwanted in a given situation that may be harmful and economically detrimental. Unwanted herbs reduce crop yield via multiferous ways of interfering with crop culture and crop growth. They compete with crops for several necessary factors like minerals, nutrients, water, and space. Hence, herbs should be eradicated regularly from fields to enhance crop growth and yield. Chemical formulations have been made that can selectively remove herb populations. These formulations are called herbicides. Herbicides usually bind with the active site of 5-enolpyruvylshikimate 3-phosphate synthase of the shikimic acid pathway, which is crucial for development and growth (Tiwari *et al.,* 2019). As a result, due to the inactivation of enzymes, herbs become yellow and die over the course of several days or weeks. Glyphosate-based chemicals, Chlorophenoxy substances, Acetanilide, Bipyridyls, and Triazines, are the common chemical formulations as herbicides.

4. Rodenticides

Rodents like rats, mole, and mice are important vertebrate pests that directly or indirectly cause distress to the growth of crops and storage of grains around the globe (Hoddle, 1999). They damage crops by gnawing, spoilage, contamination, and hoarding activities. A huge amount of crop losses is due to rodents in the world. Therefore, rodent pest control is the utmost requirement of the farming industry. Large numbers of farmers are dependent upon different rodenticides that target rats and mice. Warfarin, Bromadiolone, and Difenacoum are generally used for this purpose (Gabriel *et al.,* 2012). Such agents are anticoagulants that inhibit the enzyme vitamin K epoxide reductase, which normally reactivates vitamin K, a crucial component during the activation of several clot- ting factors responsible for the normal maintenance of life in vertebrates (Gabriel *et al.,* 2012). Inhibition of the said enzyme promotes internal bleeding and subsequent death of rodents. Non-anticoagulant rodenticides vary in their mechanism of action and include Bromethalin, Strych- nine, Cholecalciferol, and Zinc phosphide. Bromethalin is a new rodenticide for the control of commensal rodents. The mechanism of action of Bromethalin is the uncoupling of oxidative phosphorylation. The brain is the primary target for Bromethalin because of its unique dependence on oxidative phosphorylation. The drug causes brain electrolyte disturbances and results in cerebral edema that ultimately results in death of rodents (van Lier and Cherry, 1988).

Pesticides: Mechanisms Of Toxicity And Environmental Impact

Pesticides are among the most commonly used worldwide, primarily for controlling pest in crops, and various applications. These chemicals are typically applied to fields via spraying, and due to their water solubility and persistence, they often run off into nearby water bodies, contaminating lakes, rivers, and streams. The impact of pesticides on aquatic environments is a growing area of concern, particularly because of their ability to persist in water and bioaccumulate in aquatic organisms. While some pesticides are very effective in crop management, their toxicological effects on aquatic species are becoming increasingly apparent. In particular, these pesticides are known to disrupt the different organ systems of fish, affecting physiological, hepatic and hematological parameters, reproduction, growth, and development (Bansal *et al.*, 2015).The primary mode of action of these herbicides is the inhibition of photosynthesis in plants, by blocking the electron transport chain in chloroplasts. However, their effects on non-target organisms, such as fish, are mediated through different pathways, which are not fully understood but are thought to involve oxidative stress, disruption of hormone signaling, and immune suppression. pesticides can interfere with the normal functioning of various organ systems, including the liver, kidney, and immune system, in addition to affecting hematological parameters. The toxicity of these chemicals may vary depending on factors such as concentration, exposure duration, and the specific species being studied. While there has been a growing body of research on the ecological impact of triazine herbicides, particularly in aquatic systems, the specific toxic effects on hematological parameters in fish remain under explored Ali *et al.* (2018). Hematological changes in fish can indicate sub-lethal stress responses and may serve as early biomarkers of contamination in aquatic ecosystems. Research suggests that exposure to various pesticides, including triazines, can lead to alterations in blood, immune cell counts, etc., in fish, which in turn affects their overall health and survival. these Parameters used as reliable indicators of the physiological state of fish exposed to environmental stressors, including toxicants. (Rajput *et al.,* 20204). Mainly these pesticides, including fungicides, insecticides, rodenticides enter aquatic systems through surface runoff, impact fish through various mechanism such as oxidative stress, endocrine disruption, neurotoxicity and behavioral changes, organ and tissue damage. These disfunctions can provide a quantitative measure of how a toxic substance, such as a pesticide affects health of the fish. Given the significant role that these parameters play in maintaining the overall health of fish, alterations in any of them can provide valuable information about the effects of pesticides on fish physiology. The study of this physiology in fish exposed to sub-lethal concentrations of pesticides will help in assessing the ecological impact of pesticide pollution and the long-term consequences for fish populations in contaminated water bodies.

Toxic Effects Of Pesticides On Fish

According to Rajput *et al.* (2024) the primary aim of their study is to find the toxic effects of pesticides on physiology of fish. Fish are worldwide distributed, ecologically important, and sensitivity to environmental pollutants. They have been used in numerous studies to assess the effects of pesticides and other pollutants on aquatic organisms. Existing research has shown that exposure to pesticides can lead to hazardous health of fish and the entire aquatic ecosystem. Some of the following disturbances caused by pesticides exposure and serve as sensitive biomarkers for assessing pesticide-induced stress and toxicological impact in aquatic organisms.

Gills: Gills are the first point of contact with contaminated water and have a large surface area for gas and ion exchange. Mallatt (1985) reviewed systematically and analyzed gill histopathological changes in fish exposed to toxicants. He reported epithelial lifting, lamellar fusion, hyperplasia, and impaired respiration as common responses to pesticide exposure. Observed effects are- Structural damage such as epithelial lifting, lamellar fusion, hemorrhage, distortion of primary/secondary lamellae, and mucus secretion. Ultrastructural disruption, red blood cell extrusion, and clumping of lamellae. Fernandes *et al.* (2003) explained how environmental pollutants, including pesticides, alter gill morphology and physiology. It emphasized gills as sensitive biomarkers for detecting aquatic pollution and respiratory stress in fish.

Liver: The liver handles xenobiotic metabolism and detoxification; pesticides often bioaccumulate here. Hinton *et al.* (1990) demonstrated that chronic pesticide exposure causes structural liver alterations such as necrosis, vacuolization, and cellular hypertrophy, making liver histology a reliable biomarker of chemical stress. Velmurugan *et al.* (2007) reported significant histopathological liver damage in freshwater fish exposed to pesticides, including hepatocyte degeneration, vascular congestion, and disrupted metabolic activity affecting detoxification processes.

Remarkable impacts are- Hepatocellular vacuolization and necrosis, Vascular congestion and hypertrophy of hepatic cells. Altered metabolic enzyme activity and oxidative stress markers. Damage here can disrupt energy metabolism, detox functions, and overall homeostasis.

Muscle: Muscles fibers provide power of locomotion, swimming through rhythmic and wavelike contractions to generate thrust. Yilmaz (2005) demonstrated pesticide accumulation in fish muscle tissue showing that contaminants persist in edible parts and pose potential health risks to human consumers. Ramesh *et al.* (2008) reported biochemical disturbances in fish exposed to pesticides, including protein depletion in muscle tissue due to metabolic stress.

Effects observed: Structural & Nutritional Impact are degeneration, necrotic areas, edema, and inflammatory infiltration in muscle fibers. Decreases in muscle protein and glycogen driven by metabolic disruption.

Kidney: The kidney manages waste excretion and osmoregulation. Fish exposure to pesticide leads to Excretory & Osmoregulatory Damage. Cengiz (2006) investigated deltamethrin toxicity in fish and found severe kidney damage, including tubular degeneration and glomerular deformation, indicating impaired excretion and osmoregulation functions. Monteiro *et al.* (2005) showed that toxicant exposure alters biochemical and histological parameters in fish kidneys, leading to reduced ion regulation capacity and physiological stress responses.

Effects observed: Tubular degeneration, glomerular deformities. Hemolysis between renal tubules and reduced hematopoietic tissue. Impairs waste removal and ion regulation. Tubular degeneration and inflammation.

Nervous system: Fulton *et al.* (2001) study identified acetylcholinesterase inhibition in fish exposed to organophosphate pesticides, confirming neurotoxicity and behavioral disturbances linked to nervous system dysfunction. Rao (2006) reviewed and summarized neurotoxic effects of organophosphate pesticides in fish, highlighting enzyme inhibition, behavioral abnormalities, oxidative stress, and long-term nervous system impairment.

Effects observed: Some pesticides alter neuronal function and neurochemical balance (e.g., AChE inhibition), potentially leading to behavioral changes and neurotoxicity.

Intestine: Zhang *et al.* (2019) revealed that pesticide exposure damages intestinal tissue in fish, causing oxidative stress, inflammation, histopathological alterations, and impaired nutrient absorption efficiency.

Effects observed: Intestinal barrier disruption, inflammation, and microbial dysbiosis. Impaired nutrient absorption and downstream effects on growth and immunity. Inflammation and oxidative stress pathways are often implicated. Barrier damage, dysbiosis, inflammation (Dong *et al.* 2025)

Reproductive system: Exposure to pesticides leads to reproductive disruption. According to Jobling *et al.* (1998) reported widespread reproductive abnormalities in wild fish due to pesticide exposure, including intersex conditions, altered sex hormone levels, and reduced reproductive success. Kim (1998), in his book comprehensively described endocrine disruption in fish caused by pesticides, emphasizing gonadal damage, hormonal imbalance, and long-term population-level reproductive effects.

Effects observed: Degeneration of ovarian follicles and abnormal seminiferous tubules. Vacuolization, necrosis in reproductive tissues. Reduced gamete quality and potential population-level effects.

Blood: Svobodova *et al.* (2003) demonstrated that pesticide exposure significantly alters hematological parameters in fish, including reduced hemoglobin levels, erythrocyte count, and immune response capacity. According to Rajput *et al.* (2024), Exposure to triazine pesticides resulted in a significant decrease in red blood cell (RBC) count, hemoglobin concentration, and hematocrit values, indicating anemia and impaired oxygen-carrying capacity of blood.

Effects observed: Alterations in white blood cell (WBC) count, reflecting immunological stress and either inflammatory response or immunosuppression in fish. Reduction in hemoglobin levels suggests that pesticides interfere with erythropoiesis and disrupt normal physiological functioning of the circulatory system. Significant changes in hematological indices such as RBC, WBC, hemoglobin, and plasma proteins demonstrate that triazine pesticides induce severe hematotoxin effects in freshwater fish (Rajput *et al.* 2024).

Conclusion

Pesticides have reported significant changes in epithelial lifting, lamellar fusion, hyperplasia, and impaired respiration in gills, as necrosis, vacuolization, and cellular hypertrophy in liver, depletion in muscle tissue, reduced ion regulation capacity in kidney, enzyme inhibition, behavioral abnormalities, oxidative stress, and long-term nervous system impairment, damages intestinal tissue in fish, causing oxidative stress, inflammation, histopathological alterations, and impaired nutrient absorption efficiency in intestine, infertility, alteration in RBC count, hemoglobin concentration, and WBC count. Similarly, exposure to pesticides has been linked to altered immune function, which could manifest in changes the health of fish species. The impact of pesticides on fish health is of great concern, particularly when considering the potential for bioaccumulation and long-term ecological effects. It is essential to understand how even sub-lethal concentrations of these pesticides can alter physiology in fish, as such changes can compromise the fish's health, growth, and reproductive success.

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