

A Review On Toxic Effects Of Fungicide On Various Physiological Aspects Of Fish

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Abstract: Ecotoxicology is the science of the effects of toxic chemicals on biological organisms, especially at the population, community, ecosystem, and biosphere levels. Pesticides, after surface runoff, enter the aquatic system, causing a hazardous condition in the environment. These agrochemicals have been reported to be highly toxic not only to the fish population but to the other organisms as well, which form the food chain of the ecosystem. The contaminations of water result in various adverse effects on the health of the fish by altering their physiological status. The fungicides cause toxic effects on the biochemical, haematological, genetic, enzymatic, protein, and histological status of the organisms. In the course of this review, an attempt has been made to explain the ill effects of the commonly used fungicides on the different species of fish by rating the toxicity levels of the toxicants. Fish metabolism is directly affected by different pesticides. They cause different types of toxicity in fish such as changes in fish behaviour, haematological changes, histopathological disturbances, biochemical modifications, endocrine system disruption, changes in antioxidant defence system and alteration of acetylcholinesterase activity. The judicious use of fungicides must be carried out by the farmers. The use of Biopesticides and natural products must be encouraged to avoid the toxic effect of the fungicides. Biocontrol of the pests must be a wise selection as compared to the use of synthetic agrochemicals. The alternations or changes that this review will cover include the following: alternations or changes that affect the behavior of the fish, such as increased breathing on the surface, tremors on the fins of the fish, gulping of air, irregular swimming, and movement of the operculum; alternations or changes that affect the biochemical characteristics of the fish, such as the damage to the antioxidant defense system of the fish due to the formation of ROS, alterations in the levels of various indicators of oxidative stress.

Keywords: Fungicides, Fish Toxicology, Oxidative Stress, Haematological Alterations, Histopathology.

I. INTRODUCTION

In the recent past, the large rate of growth in the population of humans coupled with the high rate of industrialization has led to the problem of food grain production. Another problem that has affected crop plants is the damage that is done by various kinds of pathogens such as insects, weeds, fungus, bacteria, viruses, and so on. Pesticides are those toxic substances that are biocides, that is, they kill, repel, and reduce unwanted herbs, rodents, fungi, or other organisms that impart threats to crop plants. Hence, these are being extensively used in modern agriculture practices for increasing crop production in order to meet the demands of the growing human population.

However, the lack of knowledge and excessive use of these pesticides impart lethal effects on the organisms. Once the surface runoff occurs, these toxicants get mixed with the aquatic system, thereby imparting hazardous effects on the organisms, especially fishes. The quality of water is affected by these toxic chemicals, thereby affecting the health of the fishes (1, 2). Recent studies on adult zebrafish have demonstrated that chronic exposure to mancozeb causes multi-organ toxicity characterized by oxidative stress, behavioral abnormalities, tissue damage, and impairment of antioxidant defense systems. These findings indicate that fungicide toxicity extends beyond single-organ effects and may involve systemic physiological disturbances.

Pesticides in the environment are widespread, and most of them are synthetic. The mode of exposure of these toxic chemicals in fish and aquatic animals is in three ways: Dermal- by direct absorption of these chemicals through their skin by swimming in pesticide contaminated water, Inhalation- by direct uptake of these chemicals through their gills by respiration, Orally- by drinking pesticide contaminated water or swallowing pesticide contaminated food. Among aquatic animals, fish is found to be highly susceptible to environmental contamination of water. Hence, it can be said that certain physiological processes like biochemical, haematological changes, alterations in genetic, protein, histological, and oxidative stress can be seriously affected by pollutants like pesticides in fish. Fish is found to be the most commonly consumed aquatic food, as it is rich in proteins. Hence, it is affecting human health as well. In the present paper, a review is given about the fungicidal effect of pesticides in fish in aquatic systems.

II. FUNGICIDE INDUCED TOXICITY IN FISH

A lethal concentration of Pesticide that will kill 50% of the test fish population within a specified period of exposure is usually determined after 24 to 96 hours. The exposure of fish and aquatic animals to the pesticides is dependent upon the biological factors of the pesticide, which include Bioavailability, Bioconcentration, Biomagnification, and Persistence in the environment. Bioavailability is the extent of the Fungicides are the chemicals that help in controlling fungal organisms that lead to the damage of the crop plants and fungal plant diseases. Many, recent studies have demonstrated that environmental factors such as temperature and pH significantly influence fungicide toxicity in aquatic organisms, whereas, exposure of zebrafish embryos to azoxystrobin under varying environmental conditions resulted in delayed hatching, developmental abnormalities, altered heart rate, and increased stress protein expression, suggesting that climate-related changes may enhance fungicide toxicity in freshwater ecosystems (36).

Also, difenoconazole, a widely used triazole fungicide, has recently gained attention because of its potential to induce oxidative stress, endocrine disruption, developmental toxicity, and reproductive impairment in fish. Studies suggest that chronic exposure may alter antioxidant enzyme activities and disrupt steroid hormone synthesis (37). Similarly, pesticides usage in the agricultural fields for controlling the pests is extremely toxic to the non-target species such as fish and thereby affects the health of the fish by the inhibition of metabolism, which might lead to the death of the fish. Toxicity of the pesticides in fish has already been studied by the previous researchers, and they have revealed that the pesticides at the chronic level of exposure have the capacity to induce various types of effects such as oxidative damage, inhibition of AChE activity, biochemical alterations, histopathological alterations, and haematological and developmental alterations, mutagenesis and carcinogenesis. Pesticides in the environment in association with other similar chemicals have the capacity to induce lethal and sub-lethal effects in the fish.

The Pesticides' ability to harm fish and other water-dwelling animals is mostly determined by the level of toxicity, the duration of exposure, the rate of dose, and the environmental persistence of the Pesticides. A lethal dose of Pesticides is the quantity of Pesticides that is fatal because not every member of a species will die from the toxic substance. A standard measure of the toxic dose of Pesticides, called the lethal available pesticide in the environment that is exposed to the fish and the wildlife (5). Persistence is the long-lasting breakdown of the pesticide in the environment, which may be more available for exposure to aquatic animals (6). The information given concerning the Pesticide product and the impact that the Pesticide has on the fish and aquatic life is dependent upon various factors, including the type of Pesticide product, the use of the Pesticide product, the weather, the aquatic animals, and the number of fish killed.

Table: Fungicide-Induced Toxicity in Fish

Fungicide (Class)	Common Use in Agriculture	Fish Species Studied	Major Physiological / Toxic Effects in Fish
Carbendazim (Benzimidazole)	Control of fungal diseases in cereals, fruits, and vegetables	Cyprinus carpio, Oreochromis niloticus	Hepatotoxicity, oxidative stress, reduced antioxidant enzymes, altered hematological parameters, reproductive toxicity
Mancozeb (Dithiocarbamate)	Broad-spectrum fungicide for vegetables and fruits	Danio rerio, Labeo rohita	Gill damage, endocrine disruption, reduced growth, neurotoxicity, developmental abnormalities
Propiconazole (Triazole)	Used in cereals and plantation crops	Oncorhynchus mykiss, Oreochromis mossambicus	Liver enzyme alteration, oxidative stress, endocrine disruption, impaired steroid synthesis
Tebuconazole (Triazole)	Control of rusts and leaf spots	Danio rerio, Carassius auratus	Developmental toxicity, embryonic deformities, oxidative stress, behavioral changes
Azoxystrobin (Strobilurin)	Broad-spectrum fungicide for many crops	Danio rerio, Pimephales promelas	Mitochondrial respiration inhibition, reduced ATP production, metabolic disruption
Chlorothalonil (Organochlorine fungicide)	Control of fungal leaf diseases	Oncorhynchus mykiss, Lepomis macrochirus	Acute toxicity, gill epithelial damage, respiratory distress, immune suppression
Captan (Phthalimide fungicide)	Seed treatment and fruit crop protection	Salmo trutta, Cyprinus carpio	Oxidative stress, DNA damage, decreased growth and survival
Metalaxyl (Acylalanine)	Used for oomycete fungal diseases	Danio rerio, Clarias gariepinus	Altered liver metabolism, oxidative damage, behavioral abnormalities
Thiram (Dithiocarbamate)	Seed treatment fungicide	Labeo rohita, Oncorhynchus mykiss	Neurotoxicity, gill histopathological changes, reduced enzyme activity
Copper-based fungicides (e.g., Copper oxychloride)	Control of fungal and bacterial diseases	Cyprinus carpio, Tilapia species	Ion regulation disruption, gill damage, reduced oxygen uptake, oxidative stress

III. KEY PHYSIOLOGICAL SYSTEMS AFFECTED IN FISH

Fungicides generally affect multiple physiological systems in fish, including:

















- Respiratory system: Gill damage leading to reduced oxygen exchange,
- Hepatic system: Liver dysfunction and altered detoxification enzymes,
- Haematological system: Reduced hemoglobin, RBC count, and haematocrit,
- Nervous system: Neurotoxicity and behavioral abnormalities,

Reproductive system: Endocrine disruption and reduced fertility, Antioxidant defense: Increased oxidative stress and cellular damage.

These toxicological impacts can ultimately lead to growth inhibition, immune suppression, reproductive failure, and increased mortality in fish populations, particularly in water bodies receiving agricultural runoff.

IV. EMERGING PHYSIOLOGICAL TARGETS OF FUNGICIDE TOXICITY

Source:figure based on data synthesized from Mendes et al. (2024), Dong (2024), Li et al. (2025), and Lu et al. (2024).

Physiological System	Recent Findings	Key Illustrations
 Cardiovascular System	Cardiac deformities such as pericardial edema, atrial/ventricular abnormalities and altered heartbeat frequency have been reported.	  
 Immune System	Fungicides can suppress immune functions and trigger inflammatory responses, increasing susceptibility to pathogens.	 →  → 
 Gut-Microbiome Axis	Induces oxidative stress, intestinal inflammation and apoptosis in gut tissues and disrupts the composition of gut microbial communities.	 →  → 
 Transcriptomic Responses	Alterations in the expression of genes related to oxidative stress, endocrine function, metabolism, immunity and cellular signaling pathways.	
 Developmental Biology	Causes delayed hatching, growth retardation, skeletal deformities and other embryonic abnormalities.	

V. EFFECT OF FUNGICIDES ON FISH

Rao and Pillala (6) found that fish metabolism gets directly affected by various pesticides. These pesticides cause various toxicity in fish, such as alterations in fish behavior (8-10), haematological alterations (11-13), histopathological alterations (14-17), biochemical alterations, disruption of the endocrine system (3,18,19), alterations in the antioxidant defense system (20-22), and alterations in the activity of acetylcholinesterase (23-26).

VI. BIOCHEMICAL EFFECT

It has been found in various studies that pesticides cause devastating effects on various biochemical parameters of fish. The study on *Labeo rohita* was conducted by applying organophosphates at sublethal concentration. The study found alterations in various enzymes, such as glutaminases including phosphate activated glutaminase and L-keto acid activated glutaminase in brain tissues of the fish, which was associated with the involvement of these brain regions in metabolism. Recent investigations have shown that fungicides can adversely affect intestinal physiology by

inducing oxidative stress, inflammation, and apoptosis in gut tissues. These alterations may impair nutrient absorption and disrupt gut microbial communities, thereby affecting fish growth, immunity, and overall physiological performance (39).

VII. HAEMATOLOGICAL EFFECT

Various researches have revealed the lethal effect of pesticides on hematological factors of different fish species. The blood parameters have been used to investigate the level of stress in fish exposed to various pollutants and toxicants such as heavy metals, pesticides, industrial effluents, etc. Toxicology has revealed that the effect of different fungicides on erythropoietic organs such as the kidney and spleen may lead to a reduced number of erythrocytes and haemoglobin content, which may be considered a sign of anaemic conditions, and even lead to the death of fish. A reduced number of erythrocytes and haemoglobin content in freshwater fish species *Channa punctatus* have been reported by Anees (28). A reduced percentage of lymphocytes and monocytes in *Cyprinus carpio* have been reported by Svoboda, et al. (29). A significant increase in neutrophil percentage in common carp has been reported by Banaee, et al. (30).

VIII. HISTOLOGICAL EFFECT

The toxicity of commonly used fungicides in different organs in fish include gill, heart, kidney, liver, muscle, and spleen. The effect of fungicides in gill is hyperplasia of the epithelial cells with fusion of lamellae, epithelial cell hypertrophy, edema, necrosis, and degenerative changes in the primary and secondary lamellae. Remarkable effects of the fungicides were observed in the cardiac muscles of the heart, which is associated with the circulatory system of the organism. Toxicity in the liver shows the presence of a large number of vacuoles, nuclei of the cells were enlarged, nuclear hypertrophy, enlarged sinusoids, atrophic areas in the liver cell structure in comparison to the normal cells. Nuclear and cytoplasmic degeneration along with melano macrophage is also observed. Proximal

convoluted tubules and secondary convoluted tubules were degenerated in the kidney of the fish, cellular contours not prominent. Devascularization of the kidney and innervations of short bundles of muscles, muscular dystrophy, degeneration, and disorganization were the characteristics of the toxicated fish muscles. Spleen is made of fibrous capsules, with small trabeculae extending into the parenchyma.

The parenchyma could be differentiated into red and white pulp. The enlargement of red pulp and the presence of hemosiderin granules in the melanomacrophage center are considered to be the most important histopathological damage in the spleen tissue of the fish exposed to sublethal concentrations of the fungicides. Gill histopathological damage was observed due to the exposure of mosquitofish *G. affinis* to deltamethrin (31), as well as the application of maneb and carbaryl to rainbow trout *O. mykiss* (32). Das and Mukherjee (33) investigated the toxic impact of sub-lethal doses of hexachlorocyclohexane (HCH) for a period of 45 days on the liver, kidneys, gill, skin, muscles, heart, brain, and other organs of *Labeo rohita*.

IX. GENOTOXIC EFFECT

Different studies have been conducted which throws light at genotoxic effect of pesticides on fish. There is rich documented literature witnessing research on molecular level of different fish species showing ill effects of pesticides DNA levels (34-36). Other researchers, Tripathy, et al. (37) explained that tissue-specific damage in nucleic acid content may be due to differential effects of Fenvalerate or its metabolites on synthesis and degradation of DNA or RNA in gill and kidney cells of the fish..Effect on Protein. Choudhury, et al.(20) reported that due to long term exposure of *Channa punctatus* and *Oreochromis mossambicus* to Hexaconazole 5% SC and Azoxystrobin 23% SC caused over expression of some lower molecular protein as compared to control.

X. CONCLUSION

Fungicides play an essential role in modern agriculture by protecting crops from fungal diseases and ensuring higher productivity. However, their indiscriminate and excessive use has raised serious concerns regarding their ecological consequences, particularly in aquatic ecosystems. Fish, being highly sensitive aquatic organisms, serve as important bioindicators for assessing environmental contamination caused by agrochemicals such as fungicides.

The review clearly indicates that exposure of fish to different classes of fungicides—including triazoles, strobilurins, dithiocarbamates, and benzimidazoles—can significantly alter various physiological and biochemical processes. Toxic effects have been widely reported on respiratory physiology, metabolic pathways, enzymatic activities, haematological parameters, endocrine balance, and reproductive functions. Disruption of gill structure and function leads to impaired respiration and oxygen uptake, while hepatotoxicity affects detoxification and metabolic regulation. Similarly, alterations in antioxidant defense systems and the generation of reactive oxygen species result in oxidative stress, which damages cellular components such as lipids, proteins, and nucleic acids. In addition, fungicide exposure has been shown to induce significant changes in haematological indices, including reductions in haemoglobin concentration, erythrocyte counts, and haematocrit values, which ultimately affect the overall health and survival of fish. Neurotoxicity, immunosuppression, and endocrine disruption further contribute to physiological imbalance and reduced fitness of aquatic organisms. Chronic exposure, even at sub-lethal concentrations, may impair growth, reproduction, and behavior, leading to long-term ecological consequences for fish populations.

Given the increasing contamination of freshwater bodies through agricultural runoff, there is an urgent need for careful monitoring and regulation of fungicide application. Adoption of integrated pest management (IPM), development of eco-friendly fungicides, and

promotion of sustainable agricultural practices can significantly reduce the environmental burden of these chemicals. Furthermore, advanced toxicological studies incorporating molecular, biochemical, and physiological biomarkers are necessary to better understand the mechanisms of fungicide toxicity in aquatic organisms.

Overall, protecting aquatic ecosystems from agrochemical pollution requires a balanced approach that ensures agricultural productivity while safeguarding environmental and aquatic biodiversity. Continued research, stricter regulatory frameworks, and increased awareness among farmers and stakeholders are essential to mitigate the adverse impacts of fungicides on fish and other aquatic life.

Fungicides are essential for the development of modern agriculture, protecting the crop from fungal diseases and increasing productivity. The uncontrolled and excessive use of these chemicals has created serious issues regarding their ecological impacts, particularly in aquatic environments. Fish are highly sensitive aquatic organisms that play an important role in bio-indicators for the assessment of environmental contamination by agrochemicals such as fungicides.

It is evident from the review that exposure of fish to various classes of fungicides, such as triazoles, strobilurins, dithiocarbamates, and benzimidazoles, can cause alterations in various physiological and biochemical processes. The toxic effects of these agrochemicals have been well documented on the respiratory system, metabolic pathways, enzymatic activities, hematological parameters, hormonal balance, and reproductive functions. Disruption of the gill structure and function affects the respiratory system and oxygen uptake, whereas hepatotoxicity affects the detoxification and metabolic pathways. Alteration in antioxidant enzymes and the generation of ROS cause oxidative stress, resulting in damage to cellular components such as lipids, proteins, and nucleic acids.

Moreover, exposure of fish to these agrochemicals has been reported to cause alterations in the haematological parameters, such as reduced

haemoglobin concentration, erythrocyte counts, and haematocrit values, which ultimately affect the health and survival of the fish. In view of the rising levels of contamination in freshwater bodies due to agricultural runoff, there is an urgent need to monitor and control the application of fungicides. The adoption of integrated pest management, the development of eco-friendly fungicides, and the encouragement of sustainable agriculture are some steps that could minimize the impact of these agrochemicals on the environment. Additionally, more advanced toxicological investigations with the use of molecular, biochemical, and physiological biomarkers are required to elucidate the mechanisms of toxicity of these chemicals to aquatic life.

In conclusion, the protection of aquatic life from agrochemical pollution requires a holistic approach that seeks to promote agricultural productivity while preserving biodiversity in the environment and in our aquatic ecosystems. More research needs to be conducted, and regulations should be put in place to raise awareness among farmers and other stakeholders to mitigate the adverse effects of these chemicals on fish and other aquatic life.

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