Dose-Dependent Bioaccumulation of Water-Borne Pesticides (Bifenthrin, Chlorpyrifos, and Endosulfan) in *Ctenopharyngodon idella* (Grass Carp)

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ABSTRACT

The extensive use of agricultural pesticides poses a significant threat to aquatic ecosystems, with fish being among the most vulnerable organisms due to their constant exposure to contaminated water bodies. This article investigates the dose-dependent bioaccumulation of three widely used pesticides chlorpyrifos, bifenthrin, and endosulfan in the freshwater fish species *Ctenopharyngodon idella* (grass carp). These pesticides, commonly detected in agricultural runoff, differ in their chemical properties and persistence, leading to varied accumulation patterns in fish tissues. Research indicates that bioaccumulation in lipid-rich tissues like the liver and muscles increases with exposure concentration and duration. Chlorpyrifos exhibited rapid uptake with notable neurotoxic symptoms, while endosulfan demonstrated high persistence and potential for endocrine disruption. Bifenthrin, though used in smaller quantities, showed strong bioaccumulation and behavioral alterations. The study emphasizes the ecological risks associated with chronic, low-dose exposures and highlights the need for constant monitoring, eco-friendly pest control strategies, and awareness to mitigate pesticide infiltration into aquatic food chains.

Keywords: Endosulfan, bifenthrin, chlorpyrifos, *Ctenopharyngodon idella*, bioaccumulation, neurotoxic, endocrine disruption

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Introduction

Pesticides are significant issue in almost every country. The increase in land productivity is mostly connected with the indispensable application of insecticides. Thus, the remnants have been seen in many environment sections all over in the world and it ultimately causes potential hazard of pollution in the environment [1]. Pesticide residues often enter aquatic environments through runoff from agricultural lands, posing serious threats to non-target species such as fish. These contaminated fish can then enter the food web, ultimately jeopardizing biodiversity. Given that a substantial portion of the global food supply comes from fish, ensuring their health is essential for both ecological balance and human well-being [2]. So, the one of ecotoxicology's most serious issues going forward will be the evaluation of impacts of mixture of pesticides on living organisms especially aquatic biota including fish. These pesticides are also responsible for changes in physiological and metabolic processes in aquatic biota. And these pesticides can ultimately change the whole biochemistry of aquatic animals [3]. And once their physiology has changed, their hormones and enzymes also have been disturbed. So, the animal unable to survive because of this changed endocrinology. Pesticide usage monitoring is crucial for public health, environmental stewardship, agricultural productivity, and regulatory decisions. It evaluates exposure risks, informs safety standards, and enhances crop losses through integrated pest management frameworks [4].

Sources and Pathways of Pesticides in Aquatic Environments

Pesticides enter aquatic environments through various sources and pathways, posing significant risks to water quality and aquatic life. The major sources include agricultural runoff, where pesticides applied to crops are washed into nearby rivers, lakes, and streams during rainfall or irrigation. This is one of the most common and direct routes of pesticide contamination. Moreover, urban pesticide uses in gardens, lawns, parks, and even along roadsides, adds to the problem, particularly during rains when topwater flows into water bodies without any form of filtration [5].

The other significant source is atmospheric deposition where the pesticides evaporate into the air, and later fall back on the surface either through rain or dust. Pesticides may also end up in the waterways through industrial effluents and waste water treatment plants effluents which sometimes are not properly treated before they are released into the water. Moreover, pesticides may go into the ground water via soil leaching and eventually link with surface waters [6]. The major means of transport involve the surface runoff, underground water transport, leaching, pesticide sprays, and pollutant direct drainage or spillage. When they enter the water body, the pesticides may be accumulated in the sediments, consumed by water organisms or transformed to toxic derivatives. Recognizing the causes and destinations of these sources is critical in developing strategies that would help reduce pesticide pollution as well as safeguard the water bodies.

Mechanism of Bioaccumulation

Bifenthrin, chlorpyrifos, and endosulfan are lipophilic, persistent and bioaccumulate considerably in aquatic life forms. These chemicals find their way into organisms through absorption into organisms (through the gills, skin or through ingestion of polluted waters, sediments and food). They have high affinity towards lipids; thus, they may accumulate on fatty tissue, mainly in a species that has low ability to metabolize these toxins in their bodies [7]. Bifenthrin is a synthetic pyrethroid that has high affinity to organic matter and is gradually metabolized which results in long retention in aquatic life. An example of an organophosphate that bioaccumulates is chlorpyrifos, which is converted to a more toxic compound 1-oxon-chlorpyrifos, which is less readily dispersible [8]. Endosulfan is an organochlorine pesticide that is very persistent and does not degrade easily hence rendering it one of the most bio accumulative pesticides in the aquatic life. In a long term, these pesticides can enter the food chain through biomagnification and cause tremendous dangers to the organisms in higher trophic levels [9]. They are known to accumulate to cause neurotoxic disorders, reproductive disorders, and developmental disorders and eventually alter the balance and health status of aquatic ecosystems.

Impacts of bifenthrin, chlorpyrifos, and endosulfan on *C. idella*

Toxic effects of exposure to bifenthrin, chlorpyrifos, and endosulfan have also been observed in grass carp that is a popular freshwater fish species cultured all over the world. Bifenthrin has a knock-out command on nervous system of grass carp by interfering with sodium channels, which result in abnormal movements of swimming, loss of balance and decreased feeding responses. It is also capable of producing histopathological impairment of the gill, liver and kidney tissues affecting the ability to respire and detoxify. An organophosphate called chlorpyrifos competes with the cholinesterase enzyme called acetylcholinesterase (AChE) in the nervous system leading to neurotoxicity, tremor in the muscles, respiratory toxicity, and alterations in behavior. It can also produce oxidative stress that results into the destruction of cells in some essential organs. Because of its recalcitrant and bioaccumulate features, endosulfan causes high toxicity in grass carp, such as gill injury, liver degeneration, reproductive impairments and immune suppression. The endocrine functions can also be interfered with and growth and survival decreased by chronic exposure. All in all, these pesticides are very dangerous to the health and productivity of grass carp and this may affect the aquaculture systems as well as the natural fresh water lands [10].

Monitoring and Detection Methods

The surveillance and tracking of pesticides that include bifenthrin, chlorpyrifos, and endosulfan in water systems with the use of field-based sampling, laboratory experiments, and more sophisticated methods of analysis [11]. Collection of water, sediment as well as tissue samples of aquatic organisms such as fish is a regular practice of determining the retreat of contamination. Gas Chromatography (GC) and Gas Chromatography-Mass Spectrometry (GC-MS) are the most common methods used in the detection of pesticides; they have high sensitivity and precision when used in the detection of trace pesticides in a sample [12]. HPLC-related to High-Performance Liquid Chromatography in non-technical terms and also LC-MS/MS to Liquid Chromatography-Mass Spectrometry are also the common methodology in detection and determination of pesticide residues most often in complex biological environments. Secondly, Enzyme-Linked Immunosorbent Assay (ELISA) is a quick and a semi-quantitative screening tool, which is applicable at the field level monitoring [13] [14]. In combination, these methods will help to conduct the environmental risk assessment well and regulate the use of pesticides in water bodies.

Impacts and Risk Management of Bifenthrin, Chlorpyrifos, and Endosulfan

The persistent, lipophilic pesticides, such as bifenthrin, chlorpyrifos, endosulfan, have an easy bioaccumulation stage in the water bodies in aquatic animals like grass carp. These pesticides are taken in by the fish. And their high rate of affinity with fatty tissues and their resistance to degradation make them tend to remain so deep in the life of aquatic biota and result in biomagnification throughout the trophic levels [15]. Bifenthrin has an impact on the sodium channels that influences abnormal swimming and damage of tissues. There is an inhibition of acetylcholinesterase by chlorpyrifos leading to neurooxidative stress. Endosulfan is very toxic and it induces gill damage, liver degeneration, immune suppression and reproductive effects in grass carp. In order to minimize risks, the application of integrated pest management (IPM) ought to be adapted in order to use less pesticide by utilizing biological measures and one which is less hazardous. Pesticide run offs into water bodies can be prevented by creating buffer zones and vegetative strips. There should be good storage, disposal and controlled methods of application [16]. Toxic pesticides should also be banned, especially endosulfan. Some bioremediation techniques such as microbial degradation and constructed wetlands to detoxify the polluted water. Other measures towards the sustainable pesticide management and safeguarding aquatic ecosystems include constant monitoring.

Research Gap

Although, much work has been done in terms of research on the toxicity of pesticides such as bifenthrin, chlorpyrifos and endosulfan but little is known about their integrated effects and their long term sub-lethal effects on aquatic organisms especially in the field conditions [17]. There has been scant research on bioaccumulation in the various trophic levels and chronic exposure implications on reproduction, immunity and behavior of the indigenous fish species such as grass carp. Moreover, the majority of studies deal with single compounds disregarding potential interaction of multiple contaminants found in an aquatic system that can either be synergistic or antagonistic.

Future Prospective

The research in the future should be done to engineer the pest control methods which are less harmful to the environment and also enhancement should be done to the early detection methods of the chemicals produced by the pesticides in the water. Molecular/biochemical biomarkers should be preferred in order to identify the early indications of toxicity in aquatic life. The effectiveness of the large-scale field bioremediation applications such as microbial degradation and phytoremediation should also be studied. Assimilating water quality monitoring, remote sensing and GIS tools may also be able to do more to ensure future risk prediction and water management systems of pesticide pollution.

Conclusion

The extensive application of pesticides like bifenthrin, chlorpyrifos, and endosulfan is a tremendous danger to water bodies especially grass carp which is a sensitive fish. These chemicals are bioaccumulated in aquatic biota, disruption of physiology and behavior and long-term ecological disturbance are also observed. Contamination levels should be properly monitored by sophisticated series of analytics and the application of biological indicators. Integrated pest management, enforcement to standards, use of sustainable agricultural practices is necessary to counter these risks. Further research and innovation are essential to design safer alternative, improve ways of remediating it, and guarantee that aquatic ecosystems and biodiversity are safe.

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