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Impact of Disinfectants and Insecticides on Fish Physiology

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Abstract

Aquaculture is vital for global food security, but the routine use of disinfectants and insecticides essential for disease and pest control can threaten fish health and ecosystem balance when mismanaged. Chemicals like Didecyldimethyl Ammonium Chloride (DDAC) and Cypermethrin are effective at controlling microbes and parasites, yet even low doses can cause significant harm to non-target species such as fish. These substances can accumulate in aquatic environments, damaging fish gills, disrupting nervous and endocrine systems, weakening immunity, and altering behaviour and reproduction. Chronic exposure often results in reduced growth, higher mortality, and poor fish welfare. To ensure sustainable aquaculture, it is essential to use these chemicals judiciously, favour eco-friendly alternatives like hydrogen peroxide, and implement strategies like biofilters, vegetative buffers, and biological pest control. Educating farmers on proper chemical handling and monitoring water quality can help reduce environmental impact. A balanced, science-based approach is critical to protect aquatic life while maintaining productivity in aquaculture.

Key words: Disinfectants and Insecticides, Chronic exposure, sustainable aquaculture, eco-friendly alternatives, environmental impact

Introduction

Aquaculture is expanding rapidly, now supplying a significant portion of the global fish supply. To ensure the well-being of cultured fish, the sector has embraced proactive measures in disease prevention and environmental management. Integral to these measures are disinfectants and insecticides. Disinfectants such as chlorine-based compounds, hydrogen peroxide, and quaternary ammonium compounds like Didecyldimethyl ammonium chloride (DDAC) are extensively used to sanitize water, equipment, and surfaces in hatcheries and grow-out systems, thereby reducing the microbial load and preventing disease spread (Austin and Austin, 2016). Likewise, insecticides including cypermethrin and various organophosphates are applied to control insects and ectoparasites that act as disease vectors or otherwise compromise fish welfare (Boyd and Gross, 2020; World Organisation for Animal Health, 2009; Boyd and Tucker, 2012).

While the benefits of these chemical agents come with potential risks that demand careful management. When disinfectants and insecticides are misused, overapplied, or poorly managed, they may escape their target areas via surface runoff, leaching, or accidental spills, exposing not only the intended pathogens or pests but also non-target aquatic organisms (Faria *et al.,* 2021; Rand *et al.,* 1995). For instance, even at low concentrations, cypermethrin can disrupt neural signalling in fish and trigger severe behavioural changes (Bradberry *et al.,* 2005). Similarly, DDAC, while effective as an antimicrobial, has been linked to damage in gill tissues and compromised respiratory functions. After a time, such chronic exposures can lead to physiological stress, impaired immunity, reduced reproductive success, and an overall increased vulnerability to environmental changes (Sinha *et al.,* 2020; Sharma and Ansari, 2013). These insights underscore the critical need for sustainable and strictly regulations on chemical usage in aquaculture to safeguard both fish welfare and broader aquatic ecosystem health.

Disinfectants in Aquaculture: Types and Functions

For maintaining a disease-free environment is critical in aquaculture to safeguard fish health and ensure optimum productivity. Disinfectants are extensively used in hatcheries, grow-out systems, and processing facilities to eliminate bacteria, viruses, and fungi that could otherwise trigger disease outbreaks (Austin and Austin, 2016). Yet, their application must be managed carefully, since imprecise dosages may jeopardize fish physiology.

Chlorine-Based Compounds

Chlorine-based disinfectants such as Calcium Hypochlorite and Sodium Hypochlorite are popular due to their potent oxidizing properties. These agents work by disrupting microbial cell walls and denaturing proteins, effectively neutralizing pathogens (Heidi, 2024). However, if applied beyond safe limits, residual chlorine can induce gill irritation, epithelial sloughing, and hinder oxygen exchange, creating severe risks for sensitive fish species (Marking, 1994; Sinha *et al.,* 2020).

Phenols

Phenolic disinfectants like Triclosan and methylated phenols are deployed to sanitize tanks, equipment, and nets. They interfere with the enzymes of microbes, rendering pathogens inactive. Despite their efficacy, these organic compounds are environmentally persistent. Chronic exposure in fish may lead to hepatic stress, neurotoxicity, and disruptions in metabolic and reproductive functions raising concerns over thyroid hormone balance and detoxification pathways (Brown *et al*., 2014).

Hydrogen Peroxide

Regarded as an eco-friendly option, hydrogen peroxide decomposes into water and oxygen. It is widely used to control fungal infections and bacterial gill diseases, enhancing dissolved oxygen while reducing microbial loads. Nonetheless, excessive or poorly timed applications can irritate gill tissues and produce oxidative stress, especially among juveniles (Rach *et al.,* 2000).

Quaternary Ammonium Compounds (QACs)

Didecyldimethyl Ammonium Chloride (DDAC) is a common QAC that disrupts microbial membranes. Its cationic nature, however, enables binding to fish tissues, causing gill inflammation, reduced oxygen uptake, and potential bioaccumulation, with residual impacts on benthic organisms and aquatic food webs (Rach *et al*., 2000; Faria *et al*., 2021).

Importance of DDCAC

Didecyldimethyl Ammonium Chloride (DDAC) is a quaternary ammonium compound (QAC) widely used in aquaculture disinfectant protocols. Its significance lies in its high toxicity even at trace levels fish gills are extremely sensitive to QACs, and even minimal amounts of DDAC can impair gas exchange and disrupt osmoregulatory functions. Furthermore, DDAC is a persistent chemical; it adheres to sediments so that even when the overlying water appears clean, the bottom layers can continuously release toxic residues. Over time, this persistence leads to bioaccumulation within fish tissues, potentially resulting in chronic health effects such as reduced growth, impaired immunity, and long-term physiological stress (Rach *et al.,* 2000; Faria *et al*., 2021).

Insecticides in Aquaculture: Types and Concerns

Insecticides are routinely applied in aquaculture to manage pests such as lice, midges, water beetles, and mosquito larvae that not only directly affect fish health but may also serve as disease vectors. However, while insecticides help maintain biosecurity, their off-target effects present substantial environmental and physiological risks. Once introduced into aquatic systems whether through agricultural runoff, spray drift, or improper disposal these chemicals are absorbed via gills, skin, or ingestion, thereby affecting multiple fish systems (Boyd and Tucker, 2012; Faria *et al*., 2021).

- **Organophosphates (e.g., malathion, chlorpyrifos)** inhibit acetylcholinesterase, leading to continuous nerve stimulation. Affected fish may show abnormal swimming, lethargy, and impaired predator avoidance with chronic exposure disrupting neurodevelopment and reproduction (USEPA, 2017; Rao *et al*., 2005; Martin and Wilson, 2019).

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- **Carbamates (e.g., carbaryl)** also inhibit acetylcholinesterase but degrade more rapidly; nonetheless, they can cause gill hyperplasia and oxidative stress, reducing fish survival (Tomlin, 2000; WHO, 2004).
- **Organochlorines (e.g., DDT)**, although largely banned, are concerning due to their environmental persistence and bioaccumulation, resulting in liver damage and hormonal imbalances (UNEP, 2001; Turusov *et al*., 2002).
- **Pyrethroids – Focus on Cypermethrin** is particularly dangerous to fish. Cypermethrin disrupts voltage-gated sodium channels, leading to hyperexcitation, erratic swimming, respiratory distress, and, with long-term exposure, developmental delays and reproductive failure (Bradberry *et al.,* 2005; Casida, 2011; Rodriguez *et al*., 2020).

Mechanism of Toxicity in Fish

Fish in contaminated aquatic environments are continuously exposed to chemical pollutants from both disinfectants and insecticides. The primary entry point is the gills, which owing to their vast surface area and dense capillary networks essential for gas exchange quickly absorb dissolved toxins from the water (Rand *et al.,* 1995). The skin, while serving as a protective barrier, is also permeable, especially in juvenile or scaleless species like catfish, leading to increased toxin uptake upon direct contact with contaminated water. Ingestion further adds to internal exposure, as fish consume polluted water or prey tainted with chemical residues (Faria *et al.,* 2021).

Many of these substances, such as the insecticide cypermethrin and the disinfectant DDAC, are lipophilic they dissolve readily in fats and tend to accumulate in fatty tissues, including the liver and brain. Even low daily exposures can result in bioaccumulation that eventually leads to chronic toxicity. As these toxins build up, they disrupt essential physiological processes by impairing growth, reproductive performance, and immune defence, thereby increasing fish susceptibility to diseases and environmental stressors. The penetration of toxins through multiple routes, combined with their persistence in tissues, represents a significant threat to aquatic life. Thus, the continuing exposure to these chemicals can compromise the long-term health of fish populations and destabilize aquatic ecosystems. This underscores the urgent need for improved pollution management strategies globally.

Effects on Fish Physiology

Fish exposed to disinfectants and insecticides such as Cypermethrin and Didecyldimethyl Ammonium Chloride (DDAC) often suffer from widespread physiological disruptions, affecting several organ systems. One of the most immediate impacts is on the

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respiratory system, particularly the gills. These chemicals can trigger excessive mucus production, epithelial swelling, and fusion of gill lamellae, severely hindering oxygen exchange. Affected fish may display laboured breathing, gasping at the surface, and reduced activity symptoms that point to declining oxygen uptake and increased vulnerability to infections (Sinha *et al.,* 2020).

Neurological

Neurologically, compounds like Cypermethrin interfere with nerve function by affecting voltage-gated sodium channels. This results in uncontrolled nerve firing, leading to muscle spasms, convulsions, and erratic swimming patterns. In contrast, organophosphates work by inhibiting acetylcholinesterase (AChE), causing prolonged nerve stimulation (Rao *et al.,* 2005). These disruptions severely impact normal behaviours like feeding, schooling, and predator avoidance.

Endocrine and Reproductive Effects

Chemical exposure can also cause endocrine and reproductive disturbances. Pyrethroids, such as Cypermethrin, and certain disinfectant by-products may mimic or block hormones, leading to abnormal sex development, skewed sex ratios, and reduced fertility. Long-term exposure may result in intersex conditions or diminished reproductive success, threatening population stability over time (Jobling *et al.,* 1998).

Blood and Biochemical Changes

On a biochemical level, disinfectants like DDAC induce oxidative stress, producing reactive oxygen species (ROS) that damage vital organs like the liver and kidneys. This oxidative damage can also lower haemoglobin content and suppress immune function, making fish more susceptible to diseases and environmental stressors (Velisek *et al.,* 2009).

Behavioural changes

Behavioural changes often serve as early warning signs. Fish may exhibit abnormal swimming patterns (spinning, zig-zagging), social withdrawal, or feeding avoidance. These disruptions affect not only growth and survival but also social and reproductive behaviours essential for healthy populations (Rodriguez *et al.,* 2020; Scott and Sloman, 2004).

Mitigation Straitgies

To mitigate these effects, careful and minimal use of chemicals is essential. Eco-friendly alternatives like hydrogen peroxide are recommended due to their low environmental impact (Rach *et al.,* 2000). Additionally, the integration of biofilters, vegetative buffers, and routine water quality monitoring can help manage residues. Promoting education and biological control methods further ensures the long-term sustainability of aquaculture practices (Carvalho, 2017).

Conclusion

The use of disinfectants and insecticides such as Didecyldimethyl Ammonium Chloride (DDAC) and Cypermethrin in aquaculture, while effective for disease control and pest management, poses significant environmental and physiological risks when improperly applied. These compounds exhibit high toxicity toward non-target aquatic organisms, particularly fish, leading to adverse effects on respiratory function, neurophysiology, reproduction, and behaviour. Chronic or repeated exposure can result in immunosuppression, impaired growth, reproductive failure, and increased mortality, thereby compromising the long-term sustainability of aquaculture systems. Furthermore, the environmental persistence and bioaccumulation potential of these chemicals exacerbate their ecological impact. Effective mitigation requires the application of scientifically recommended dosages, routine water quality assessments, and the substitution of hazardous compounds with eco-friendly alternatives such as hydrogen peroxide. Additional strategies, including the use of biofiltration units, vegetative buffer zones, and biological pest control agents, can further reduce chemical runoff. Promoting farmer education on safe handling practices is essential for minimizing risks and ensuring environmentally responsible aquaculture.

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