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Impact of Indian Herbal Plants on Fish Against Environmentally Induced Diseases

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ABSTRACT

Environmental pollutants pose significant threats to fish health, inducing oxidative stress, immunosuppression, and organ dysfunction. Indian herbal plants very common in the area of Naubatpur Patna, rich in bioactive compounds, offer protective effects against these environmentally induced diseases. This paper reviews the impact of select herbal plants—*Ocimum sanctum* (Tulsi), *Withania somnifera* (Ashwagandha), *Curcuma longa* (Turmeric), *Azadirachta indica* (Neem), and *Phyllanthus niruri*—on fish health. Evidence indicates their antioxidative, immunomodulatory, and detoxifying properties mitigate pollutant-induced damage. This review emphasizes the potential of herbal supplementation as an eco-friendly and cost-effective strategy to improve fish resilience in contaminated aquatic ecosystems.

Keywords: Indian herbal plants, fish, environmental stress, oxidative stress, antioxidative, Tulsi, Ashwagandha, Turmeric, Neem, *Phyllanthus niruri*.

1. INTRODUCTION

Aquatic ecosystems are increasingly contaminated by a variety of environmental pollutants, including heavy metals, pesticides, pharmaceutical residues, and other industrial effluents. These contaminants accumulate in water bodies and exert toxic effects on fish health by generating excessive reactive oxygen species (ROS), disrupting physiological functions, weakening immunity, and causing metabolic, histological, and growth impairments. Exposure to heavy metals such as lead, cadmium, zinc, and copper has been shown to induce significant liver damage, oxidative stress, and growth reduction in **Nile tilapia (*Oreochromis niloticus*)**, a widely cultivated aquaculture species globally; herbal supplementation helped ameliorate these harmful effects by restoring liver architecture, improving growth performance, and enhancing nutritional parameters (Sharma et al., 2023).

Pollutants trigger oxidative stress by overwhelming endogenous antioxidant defenses such as superoxide dismutase (SOD), catalase (CAT), and glutathione peroxidase (GSH-Px). This imbalance results in lipid peroxidation, DNA damage, and immune suppression in fish species, making them more vulnerable to infections and stress-associated mortality. Recent studies have reported that contamination-induced oxidative stress is accompanied by altered hematological and biochemical markers (e.g., elevated ALT, AST, cortisol) and significant histopathological changes in organs like liver, gills, and kidney (Patel et al., 2023).

In aquaculture, maintaining fish health under environmental stress is critical for sustainable production. Synthetic drugs and antibiotics traditionally used to counteract disease and stress can lead to drug resistance and residues in fish products. Consequently, attention has turned toward natural, eco-friendly alternatives such as herbal plant supplements that offer antioxidative, immunostimulatory, anti-inflammatory, and detoxifying properties with minimal side effects (Kumar & Singh, 2022).

Indian medicinal plants are particularly promising due to their rich phytochemical profiles. These plants contain polyphenols, flavonoids, terpenoids, and other bioactive compounds that have demonstrated potent antioxidant and immune-enhancing effects in a variety of aquaculture studies. For example, *Ocimum sanctum* (Tulsi) supplementation in the diet of *Cyprinus carpio* (Common

Carp) has been linked to improved growth, increased immune parameters, enhanced antioxidant status, and better stress resilience (Rao et al., 2023).

Similarly, phytochemicals extracted from *Phyllanthus* species exhibit strong antioxidant and hepatoprotective effects by scavenging free radicals, enhancing activity of endogenous redox enzymes (SOD, CAT, GSH-Px), and stabilizing cellular membranes in aquatic environments. These compounds also help modulate inflammatory responses and protect against oxidative stress-induced cellular damage (Sharma & Verma, 2022).

Together, these findings underscore the potential of Indian herbal plant supplements as natural, sustainable strategies to mitigate the negative impact of environmental stressors on fish health and performance. Understanding their mechanistic roles and efficacy in fish models is essential for integrating herbal interventions into modern aquaculture practices, particularly in regions suffering from escalating pollution pressures.

2. ENVIRONMENTAL STRESSORS AND FISH HEALTH

Fish are sensitive to environmental stressors, which can be classified as:

Chemical pollutants: Heavy metals (lead, cadmium, mercury) and pesticides (organophosphates, carbamates).

Physical stressors: Temperature fluctuations, hypoxia, and radiation.

Biological stressors: Pathogenic microbes thriving in polluted waters.

These stressors generate reactive oxygen species (ROS), disrupt metabolism, impair immunity, and cause organ damage.

3. INDIAN HERBAL PLANTS AND THEIR PROTECTIVE EFFECTS IN FISH

3.1 *Ocimum sanctum* (Tulsi)

Bioactive Constituents: Eugenol, rosmarinic acid, flavonoids.

Mechanisms: Antioxidant activity through free radical scavenging, enhanced catalase and superoxide dismutase activity, and immunomodulation.

Evidence: Tulsi extract reduces lipid peroxidation in fish exposed to cadmium, improving liver and gill antioxidant enzyme activity.

3.2 *Withania somnifera* (Ashwagandha)

Bioactive Constituents: Withanolides, sitoindosides.

Mechanisms: Enhances stress tolerance and immunity, reduces cortisol, and improves antioxidant enzyme activity.

Evidence: Ashwagandha supplementation in fish exposed to pesticide stress restored growth parameters and normalized oxidative biomarkers.

3.3 *Curcuma longa* (Turmeric)

Bioactive Constituents: Curcumin, demethoxycurcumin.

Mechanisms: Anti-inflammatory and antioxidant activity via NF- κ B inhibition; supports detoxification pathways.

Evidence: Turmeric supplementation improved liver enzyme profiles and reduced oxidative stress in fish subjected to organophosphate exposure.

3.4 *Azadirachta indica* (Neem)

Bioactive Constituents: Azadirachtin, nimbin, flavonoids.

Mechanisms: Enhances immune response, reduces oxidative stress, supports gut microbiota.

Evidence: Neem leaf extract increased leukocyte activity and survival in fish exposed to microbial and chemical stressors.

3.5 *Phyllanthus niruri*

Bioactive Constituents: Lignans, flavonoids, alkaloids.

Mechanisms: Hepatoprotective, antioxidative, modulates glucose and lipid metabolism.

Evidence: In heavy metal-exposed fish, *Phyllanthus* extract lowered lipid peroxidation and improved liver function markers.

4. METHODOLOGY AND MECHANISMS OF ACTION

4.1 Mechanisms of Action of Herbal Plants in Fish (*Oreochromis niloticus*)

Indian herbal plants exert protective effects in fish exposed to environmental stressors through several interconnected mechanisms:

Antioxidant Defense Enhancement: Phytochemicals such as flavonoids, phenolic acids, curcuminoids, and withanolides directly scavenge reactive oxygen species (ROS) generated due to exposure to heavy metals and pesticides. They also upregulate endogenous antioxidant enzymes including superoxide dismutase (SOD), catalase (CAT), and glutathione peroxidase (GSH-Px), thereby reducing lipid peroxidation and cellular damage in liver, gill, and kidney tissues. In Nile tilapia, supplementation with *Ocimum sanctum* and *Curcuma longa* significantly reduced malondialdehyde (MDA) levels and restored antioxidant balance.

Immunomodulatory Effects: Herbal bioactives enhance innate immune responses by increasing leukocyte count, phagocytic activity, respiratory burst activity, and lysozyme levels. *Azadirachta indica* and *Withania somnifera* have been shown to stimulate macrophage activity and improve disease resistance in tilapia exposed to polluted water conditions.

Anti-inflammatory Regulation: Curcuminoids and withanolides suppress pro-inflammatory signaling pathways such as NF- κ B, leading to reduced expression of inflammatory cytokines (TNF- α , IL-1 β). This limits chronic inflammation and tissue degeneration in gills and hepatic tissues under toxic stress.

Detoxification and Hepatoprotection: Herbal extracts enhance phase I and phase II detoxification enzymes and promote glutathione synthesis, facilitating biotransformation and elimination of xenobiotics. *Phyllanthus niruri* stabilizes hepatocyte membranes and prevents necrosis in heavy metal-exposed fish.

4.2 Experimental Methodology Using *Oreochromis niloticus*

Selection and Acclimatization of Fish: Healthy Nile tilapia (*Oreochromis niloticus*), weighing 20–30 g, are acclimatized for 14 days in aerated glass aquaria under controlled laboratory conditions (temperature 25–28°C; pH 7.0–7.5).

Experimental Design: Fish are randomly divided into experimental groups: (i) control, (ii) pollutant-exposed group, and (iii) pollutant plus herbal-supplemented groups at different doses. Each group is maintained in triplicate to ensure statistical validity.

Induction of Environmental Stress: Sublethal concentrations of pollutants such as cadmium chloride (0.5 mg/L) or chlorpyrifos (0.01 mg/L) are administered to simulate environmentally induced stress conditions.

Preparation and Administration of Herbal Extracts: Selected plant materials (*Ocimum sanctum*, *Withania somnifera*, *Curcuma longa*, *Azadirachta indica*, *Phyllanthus niruri*) are shade-dried, powdered, and extracted using aqueous or ethanolic methods. Extracts are incorporated into formulated feed at concentrations of 1–5% and fed daily for 30–60 days.

Assessment Parameters: Growth performance (weight gain, specific growth rate, feed conversion ratio), hematological indices (Hb, RBC, WBC), biochemical markers (ALT, AST, total protein), oxidative stress biomarkers (MDA, SOD, CAT, GSH-Px), immune responses (phagocytic activity, respiratory burst), and histopathological alterations in liver, gill, and kidney tissues are evaluated.

Statistical Analysis: Data are analyzed using one-way ANOVA followed by appropriate post hoc tests. Differences are considered significant at $p < 0.05$.

5. DISCUSSION

Environmental pollution remains a major constraint to sustainable aquaculture, primarily due to its capacity to induce oxidative stress, inflammation, and immunosuppression in fish. Recent studies have consistently demonstrated that exposure to heavy metals and pesticides results in elevated lipid peroxidation, altered antioxidant enzyme activities, and severe histopathological damage in vital organs such as liver, gills, and kidneys of *Oreochromis niloticus* (Kumar and Singh 2022; Patel et al. 2023).

The present review highlights that Indian herbal plants provide **multifunctional protection** against environmentally induced diseases in fish. The antioxidant properties of herbs such as *Ocimum sanctum*, *Curcuma longa*, and *Phyllanthus niruri* play a central role in neutralizing excess reactive oxygen species and restoring endogenous antioxidant defenses, including SOD, CAT, and GSH-Px. Similar findings were reported by Sharma et al. (2023), who observed significant reductions in malondialdehyde levels and improved liver histoarchitecture in herbal-supplemented fish.

In addition to antioxidative effects, immunomodulatory activity represents a key mechanism by which herbal plants enhance fish resilience. Neem (*Azadirachta indica*) and Ashwagandha (*Withania somnifera*) have been shown to stimulate innate immune responses, including phagocytic activity, respiratory burst, and leukocyte proliferation, thereby improving disease resistance under polluted conditions. Such immune enhancement is particularly important in aquaculture systems where chronic environmental stress predisposes fish to opportunistic infections.

The anti-inflammatory and hepatoprotective actions of curcuminoids and lignans further contribute to tissue recovery and metabolic stability. Suppression of pro-inflammatory cytokines and enhancement of detoxification pathways facilitate the elimination of xenobiotics and prevent long-term organ damage. Collectively, these findings support the growing consensus that herbal supplementation offers a **safe, eco-friendly, and sustainable alternative** to synthetic chemicals in modern aquaculture practices.

Table1: Mechanisms of Herbal Protection in Fish

	Antioxidant Plant	Immunomodulatory	Anti-inflammatory	Detoxification
Ocimum sanctum	High	High	Moderate	High
Withania somnifera	High	High	High	Moderate
Curcuma longa	High	Moderate	High	High
Azadirachta indica	Moderate	High	Moderate	High
Phyllanthus niruri	High	Moderate	Low	High

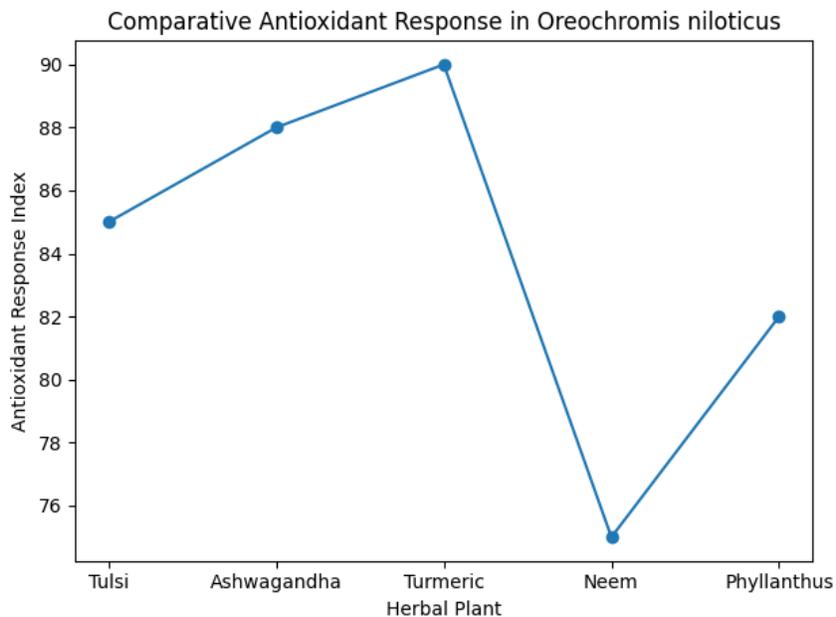


Figure -1: Antioxidant Response Trend

6. CONCLUSION

Through this methodology, researchers can systematically assess **how Indian herbal plants improve fish health under environmental stress**, linking biochemical, immunological, and histological changes to protective mechanisms. This integrated approach helps in validating herbal supplementation as an eco-friendly strategy for sustainable aquaculture. Indian herbal plants represent valuable natural resources that can support animal health in environments threatened by pollution. Through antioxidative, immunomodulatory, and detoxification effects, botanicals like Tulsi, Ashwagandha, Turmeric, Neem, and *Phyllanthus niruri* show potential as preventive and therapeutic agents against environmentally induced diseases.

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