From Coast to Culture: Ethnoveterinary Applications of Mangrove Leaf Extracts in Carp Aquaculture

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Abstract
Intensification in carp aquaculture across South and Southeast Asia has drastically escalated the incidence of devastating bacterial infections, notably motile aeromonad septicemia (MAS) caused by *Aeromonas hydrophila*. While commercial aquaculture has historically leaned on synthetic antibiotics, this dependency has fueled multi-drug resistance, public health concerns over chemical residues, and systemic oxidative stress in fish. Consequently, structural shifts toward sustainable ethnoveterinary alternatives are underway. Mangrove ecosystems represent a highly resilient botanical frontier; because these halophytes thrive under hypersaline, tidal, and microbial stress, they synthesize unique, potent profiles of secondary metabolites.
This review synthesizes recent empirical advancements in using mangrove leaf extracts—specifically from *Acanthus ilicifolius* and *Avicennia marina*—to combat bacterial pathogens in major carp species like Rohu (*Labeo rohita*). Furthermore, it highlights how integrating traditional ecological knowledge (TEK) or indigenous practices regarding seasonal harvesting and solid-state processing can optimize modern bioprocessing and extract efficacy, providing an eco-friendly path forward for fish health management.

Keywords-Mangroves, Carps, Medicinal importance, Prophylaxis

1. Introduction

Carp farming forms the backbone of freshwater aquaculture across Asia, with species like Rohu (*Labeo rohita*) and Common Carp (*Cyprinus carpio*) dominating global production yields. However, the shift from traditional extensive ponds to high-density, intensive farming systems has disrupted local aquatic equilibriums. High stocking densities, fluctuating dissolved oxygen, and accumulated organic loads induce chronic metabolic stress, compromising the host immune system and triggering virulent disease outbreaks (Sravya et al., 2025).
Among these, *Aeromonas hydrophila* and *Pseudomonas aeruginosa* present the most critical infectious threats, causing conditions like hemorrhagic septicemia, fin rot, and rapid mortality. For decades, broad-spectrum antibiotics (such as oxytetracycline and amoxicillin) served as the primary line of defense. However, prolonged prophylactic and therapeutic application has resulted in severe environmental setbacks:

- **The spread of multi-drug resistant (MDR) bacterial strains** via horizontal gene transfer.
- **Persistent tissue residues** within harvested fish, violating international export and food safety standards.
- **Host toxicity**, specifically driving lipid peroxidation and suppressing internal antioxidant enzymes in carp fingerlings.

To address these vulnerabilities, researchers are turning to ethnoveterinary pharmacology (Reverter et al., 2017). Mangrove plants present a compelling solution. Operating as specialized, stress-tolerant halophytes at the land-sea interface, mangroves possess evolutionary biochemical adaptations that terrestrial flora lack, rendering them highly effective candidates for natural aquaculture therapeutics.

2. The Mangrove Phytochemical Arsenal

The hostile intertidal zones inhabited by mangroves require robust internal defence mechanisms. Their leaves act as major biosynthetic hubs, producing a dense array of bioactive secondary metabolites designed to deter herbivory and prevent systemic microbial colonization. When extracted, these fractions exhibit direct antibacterial and immunomodulatory properties.

The specific therapeutic activities of these compounds include:

- **Total Phenolic Content (TPC) & Total Flavonoid Content (TFC):** These compounds serve as the primary drivers of antimicrobial action. Phenols directly alter cell wall structure, disrupting cytoplasmic membrane integrity and causing the leakage of essential intracellular ions. Concurrently, flavonoids inhibit bacterial motility and disrupt structural proteins.
- **Tannins:** These polymeric phenolic substances act as powerful astringents. They bind to and inactivate bacterial surface adhesion proteins, rendering the pathogen incapable of colonizing host tissues, while effectively chelating environmental iron to starve the bacteria of essential nutrients.
- **Saponins & Terpenoids:** Saponins act as natural surfactants, increasing cell membrane permeability to induce lysosomal disruption. Recent gas chromatography-mass spectrometry (GC-MS) analyses of purified mangrove leaf fractions have identified volatile sulfur- and phosphorus-bearing compounds—such as 2-propanethiol,thioacetic acid, and various alkylphosphines—that exhibit acute bactericidal properties (Sravya et al., 2023; Sravya et al., 2025).

3. In Vitro and In Vivo Efficacy in Carp Culture

Recent empirical validation has confirmed the traditional use of mangrove extracts, demonstrating high efficacy both in laboratory agar assays and live challenge trials.

In Vitro Pathogen Inhibition

When tested via disc and well-diffusion methods, organic solvent extracts consistently outperform raw water decoctions. Methanolic and ethyl acetate extracts of *Acanthus ilicifolius* and *Avicennia marina* produce clear zones of inhibition ranging from 3.2 ± 0.8 mm up to 5.9 ± 0.5 mm against virulent strains of *A. hydrophila* and *P. aeruginosa* (Sravya et al., 2023; Sravya et al., 2025). The minimum inhibitory concentration (MIC) for highly purified fractions falls within accessible microgram ranges, indicating strong therapeutic potential.

In Vivo Survival and Immunostimulation

The true value of mangrove extracts lies in their systemic performance when incorporated into fish feed. In controlled challenge trials where *Labeo rohita* fingerlings were subjected to lethal injection doses of *A. hydrophila*, the divergence between treated and untreated groups was stark:

Treatment Group (L. rohita)	In Vivo Survival Rate (%)	Impact on Host Antioxidant Markers (CAT / SOD)
Negative Control (Infected, Untreated)	0%	Severe depletion; systemic oxidative cell crash
Positive Control (Oxytetracycline @ 20 µg/mL)	71%	Moderate stabilization; risk of tissue residue
Crude Mangrove Leaf Extract (A. ilicifolius)	81%	High recovery; elevated enzyme synthesis
Purified Mangrove Fraction (AM2 Band)	94%	Peak recovery; Catalase and SOD maximized

Beyond preventing direct mortality, these plant compounds function as potent non-specific immunostimulants. Carps fed with optimized leaf extract inclusions exhibit a significant up-regulation of primary defence mechanisms. Phagocytic activity improves, leukocyte counts stabilize rapidly post-infection, and critical endogenous antioxidant enzymes—specifically Catalase (CAT) and Superoxide Dismutase (SOD)—show significant elevation (Sravya et al., 2025). This boost in antioxidant capacity neutralizes reactive oxygen species (ROS) generated during infection, protecting hepatic and splenic tissues from cellular degradation.

4. Integrating Indigenous Knowledge with Modern Bioprocessing

Coastal communities have long utilized mangrove leaves in traditional ethnoveterinary medicine to treat skin ulcers, fin rot, and parasites in localized brackish holding ponds. Integrating this indigenous knowledge with modern pharmacology optimizes extraction efficiency and preserves delicate bioactive profiles.

1.Indigenous Harvesting Protocols: Phenological Targeting.

Select mature, deep-green leaves from healthy wild stands during low-tide cycles. Traditional practices advise against utilizing yellowing, senescent, or naturally shed leaves, as their volatile sulfur compounds and active phenols degrade rapidly prior to leaf drop.

2.Thermal Mitigation & Processing: Shade Drying.

Dehydrate the collected biomass exclusively via air-drying in shaded, well-ventilated environments. Direct sun drying or high-heat oven dehydration denatures sensitive flavonoids and breaks down critical glycosides. Once crispy, the leaves are mechanically milled into a fine, uniform powder.

3.Targeted Solvent Extraction: Soxhlet or Maceration.

Extract the milled powder using organic solvents (such as 80% methanol or ethyl acetate) to isolate hydrophobic phytocompounds like terpenoids, which traditional water-boiling methods leave behind. The solution is filtered and concentrated via rotary evaporation to yield a rich, solvent-free crude paste.

4.Aquaculture Feed Formulation: Top-Coating and Delivery.
Incorporate the concentrated paste directly into commercial extruded carp feed pellets. Using indigenous binders like unrefined fish oils or natural gelatin ensures the extract remains structurally adhered to the pellet matrix, preventing nutrient leaching upon water immersion and maximizing intestinal absorption.

5. Challenges, Sustainability, and Future Prospects

While the therapeutic potential of mangrove leaf extracts is clear, moving from laboratory validation to commercial aquaculture requires addressing several logistical and ecological challenges:

- **Ecological Preservation:** Mangrove forests are fragile, highly protected ecosystems. Widespread wild harvesting of leaves to support commercial aquaculture scales could cause severe habitat degradation. Future expansion must rely on utilizing pruned biowaste from regulated coastal management zones or establishing dedicated mangrove agro-forestry plots.
- **Standardization of Dosages:** Phytochemical concentrations fluctuate naturally based on seasonal shifts, geographic salinity levels, and localized soil composition. Standardizing crude extract applications into uniform, measurable commercial doses remain a key operational hurdle.
- **Long-Term Safety Mapping:** Although short-term fingerling survival rates are highly promising, further comprehensive research is required to map long-term bioaccumulation, potential chronic hepatotoxicity at elevated inclusion limits, and clearing times within muscular tissues prior to human consumption.

6. Conclusion

Integrating indigenous knowledge with modern scientific bioprocessing establishes mangrove leaf extracts as a highly viable alternative to synthetic antibiotics in carp aquaculture. Leaf extracts from species like *Acanthus ilicifolius* and *Avicennia marina* provide a dual-action defense mechanism: delivering direct bactericidal action against persistent pathogens like *Aeromonas hydrophila* while boosting the natural structural immunity and antioxidant defenses of the host. Transitioning to these eco-friendly, biodegradable therapeutics offers a sustainable path forward, helping the carp farming industry reduce its reliance on chemical interventions and align with global food safety standards.

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